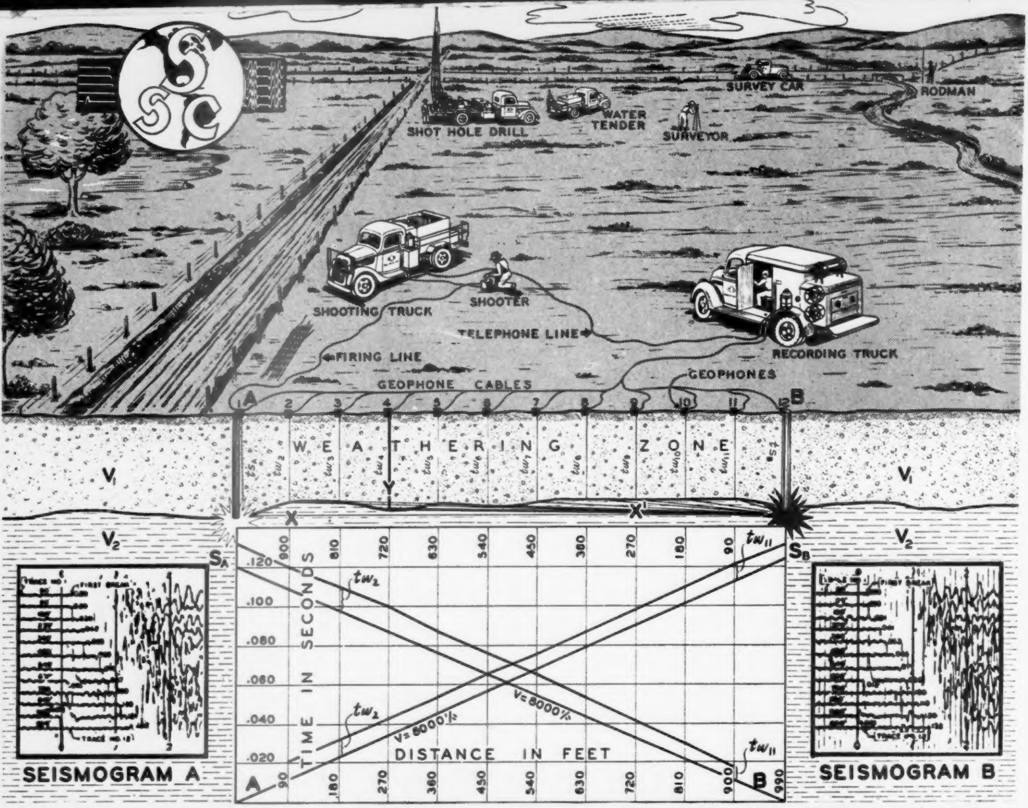
ĸпг

Volume 31 FEBRUARY, 1947 Number 2

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS


SHOT HOLE DRILL
WATER TENDER
SURVEY CAR
RODMAN
SURVEYOR
SHOOTING TRUCK
SHOOTER
TELEPHONE LINE
FIRING LINE
RECORDING TRUCK
GEOPHONES
GEOPHONE CABLES
WEATHERING ZONE
V1
V2
SEISMOGRAM A
SEISMOGRAM B
TIME IN SECONDS
DISTANCE IN FEET
V=8000'/s

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, 708 WRIGHT BUILDING, TULSA, OKLAHOMA

THE BULLETIN is published by the Association on the 15th of each month.

EDITORIAL AND PUBLICATION OFFICE AND ASSOCIATION HEADQUARTERS, 708 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma. Post Office, Box 979, Tulsa 1.

BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is $15 per year (separate numbers, $1.50), prepaid to addresses in the United States; outside the United States, $15.40.

CLAIMS FOR NON-RECEIPT must be sent within 3 months of date of publication, to be filled gratis.

BACK NUMBERS, if available, may be ordered from Headquarters. Price list on request.

	Mem.	*Non-Mem.*
Cloth-bound Bulletin, Vols. 12 (1928)–15 (1931) incl., each	$5.00	$ 6.00

SPECIAL PUBLICATIONS	*Mem.*	*Non-Mem.*	SPECIAL PUBLICATIONS	*Mem.*	*Non-Mem.*
1936. Geology of Tampico Region	3.50	4.50	1941 Future Oil Provinces, U. S. & Canada	1.00	1.50
1936. Map of Southern California	.50	.50	1941. Stratigraphic Oil Fields	4.50	5.50
1938. Miocene Stratigraphy of California	4.50	5.00	1944. Tectonic Map of U. S.	2.00	2.00

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

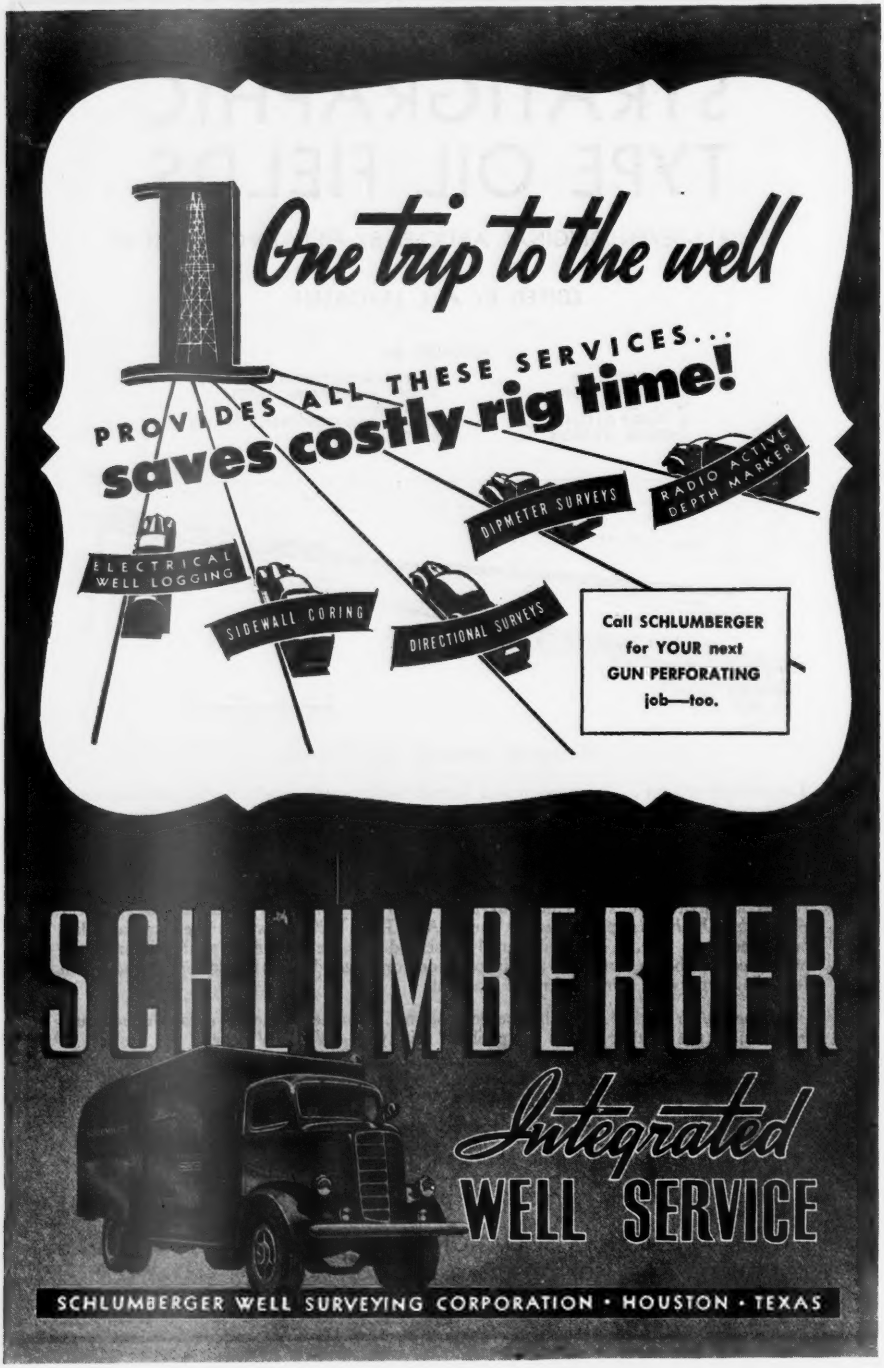
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

J. P. D. HULL, BUSINESS MANAGER
ELMER W. ELLSWORTH, ASSISTANT BUSINESS MANAGER
BOX 979, TULSA, 1, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.


One trip to the well
PROVIDES ALL THESE SERVICES...
saves costly rig time!
ELECTRICAL WELL LOGGING
SIDEWALL CORING
DIRECTIONAL SURVEYS
DIPMETER SURVEYS
RADIO ACTIVE DEPTH MARKER
Call SCHLUMBERGER for YOUR next GUN PERFORATING job—too.
SCHLUMBERGER
Integrated WELL SERVICE
SCHLUMBERGER WELL SURVEYING CORPORATION · HOUSTON · TEXAS

Bulletin Advertisers

PROFESSIONAL CARDS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

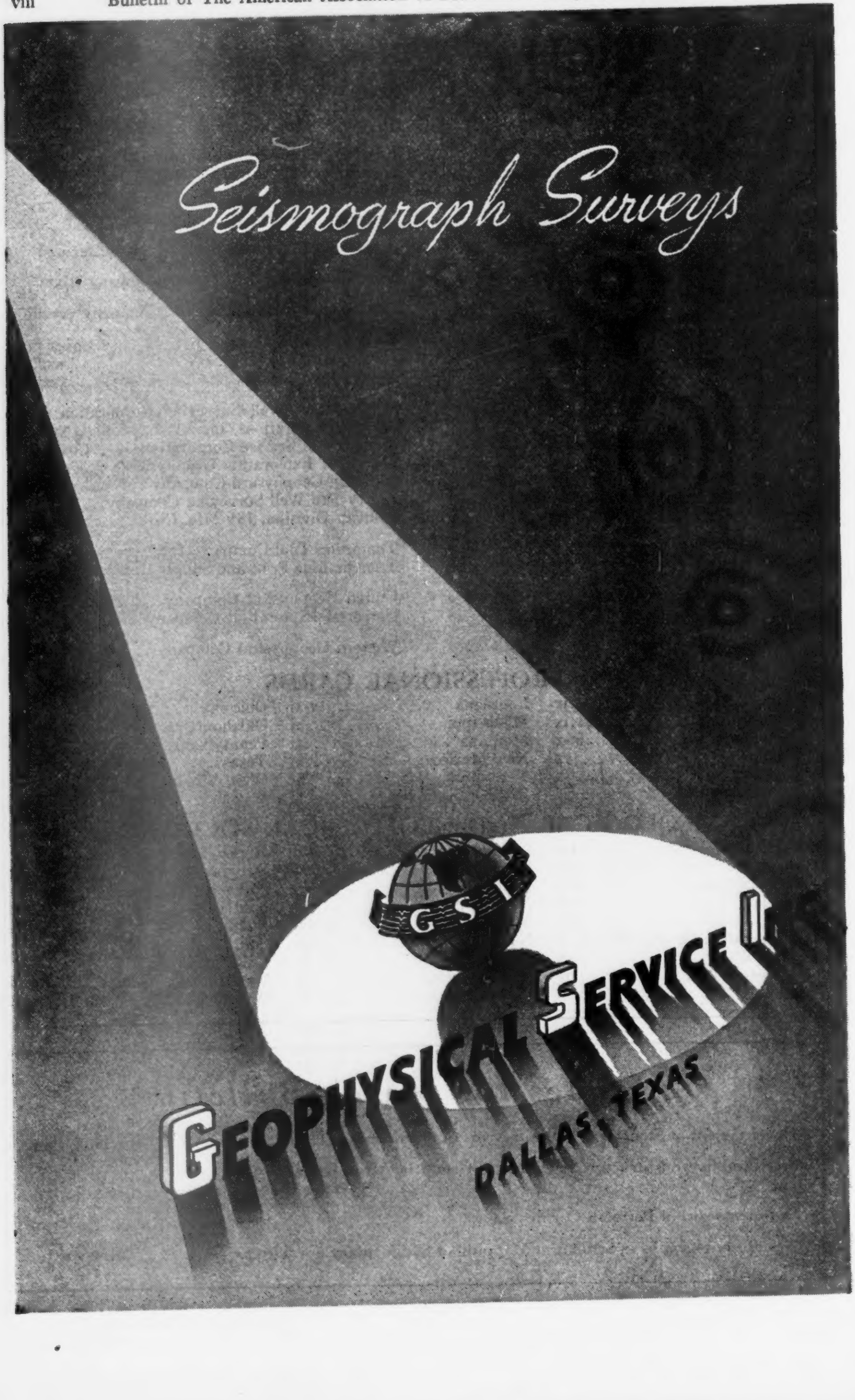
Articles for March *Bulletin*

Development of Structures in Basin Areas of Northeastern United States By J. R. LOCKETT

Stratigraphy and Structure of Traverse Group in Afton-Onaway Area By W. A. KELLY and J. WENDELL SMITH

Sedimentation in Permian Castile Sea By RALPH H. KING

Aerial Photographs in Structural Mapping of Sedimentary Formations By L. E. NUGENT, JR.


Seismograph Surveys
GSI
GEOPHYSICAL SERVICE INC
DALLAS, TEXAS

Volume 31 Number 2

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

FEBRUARY, 1947

DIASTROPHISM DURING HISTORIC TIME IN GULF COASTAL PLAIN[1]

MARTIN M. SHEETS[2]
Houston, Texas

ABSTRACT

The Gulf Coastal Plain is an area of active diastrophism. Five classes of evidence are discussed—earthquakes, fissures and faulting, regional warping, local subsidence and uplift, and pseudo-diastrophic features.

Although the Gulf Coast is described as an area of low seismicity, many earthquakes have occurred in the past and more should be expected in the future. Fissuring and faulting have been taking place in the Gulf Coast during historic time. The same statement is true for regional warping. Many cases of local subsidence have been recorded and in some localities subsidence and uplift are taking place to-day. Hoskins Mound salt dome is believed to have risen ½ foot in 23 years.

Much of the diastrophism occurring in the Gulf Coast is believed to be the result of the force of gravity. Two important factors influencing such diastrophism are, local inequalities in support and large local variations in density. Where such conditions and forces are present, compaction of the sediments by grain rearrangement often influences the form which results and may in some cases be a cause of diastrophism. Compaction may be aided by microseisms. The writer asks if the warping noted might be the result of waves in the earth's crust traveling at geologically slow speeds. The basin of the Gulf of Mexico is compared with a shallow rubber pan partly filled with stiff mud which is constantly being stretched, squeezed, and warped.

Many diastrophic features affect physiography and can be traced by use of aerial photographs even where they can not be followed on the ground. More publicity should be given to the subject of historic diastrophism to encourage individuals to make known their personal observations.

INTRODUCTION

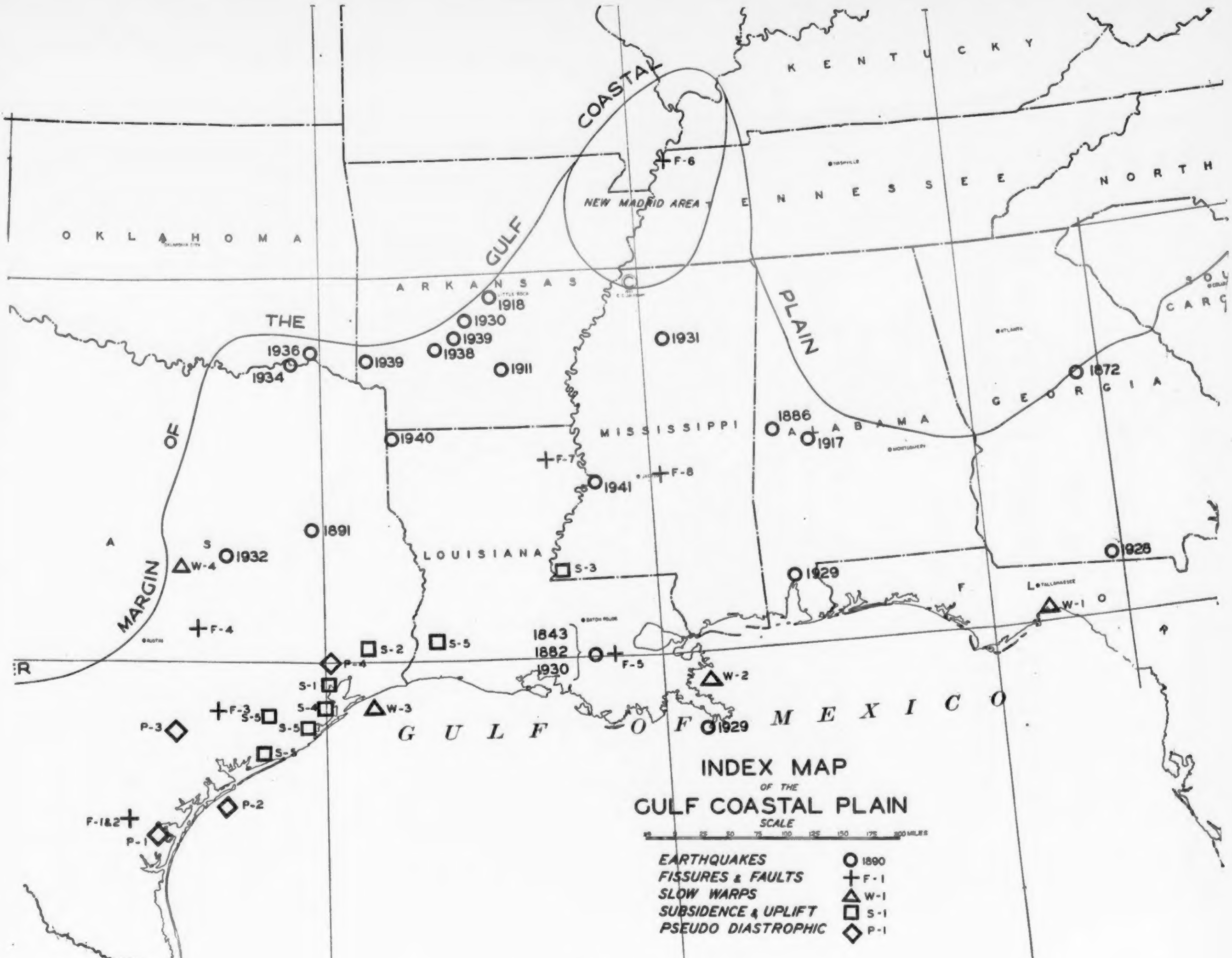
No report of this nature should ever be considered complete or final. There is undoubtedly much evidence of diastrophic activity in the Gulf Coastal Plain of which the writer is not aware. This paper therefore extends an open invitation to everyone, whether technical or non-technical, to add further information.

[1] Read before the Association at Chicago, April 3, 1946. Manuscript received, August 8, 1946.

[2] Division geophysical coordinator, Stanolind Oil and Gas Company. Much information, especially on the later parts of this paper, was gathered by personal communication. In this regard, the writer is indebted to a great many people, including the following: Wallace G. Thompson, E. H. Sellards, John M. Vetter, N. A. Rose, K. A. Maring, Watson H. Monroe, A. W. Weeks, Frank Bryan, Paul Weaver, R. H. Goodrich, C. M. Sampson, Albert G. Wolf, Glen Stewart.

Thanks are due Miss Dorothy Tips and Mrs. Sibyl Morton for assistance in preparation of the manuscript.

The writer is indebted to the Mississippi River Commission, the United States Geological



THE GULF COASTAL PLAIN
MARGIN OF
OKLAHOMA
ARKANSAS
KENTUCKY
TENNESSEE
NORTH
MISSISSIPPI
ALABAMA
GEORGIA
LOUISIANA
NEW MADRID AREA
GULF OF MEXICO
INDEX MAP
OF THE
GULF COASTAL PLAIN
SCALE
EARTHQUAKES 1890
FISSURES & FAULTS F-1
SLOW WARPS W-1
SUBSIDENCE & UPLIFT S-1
PSEUDO DIASTROPHIC P-1

FIG. I

The boundary of the Coastal Plain was adopted as that shown by N. M. Fenneman[3] on his physiographic map of the United States. In most places, this boundary corresponds approximately with the contact of the Cretaceous sediments on older formations. The area was limited on the southwest by the Rio Grande and on the east by the meridian of 83° W. Longitude.

EARTHQUAKES

Records of earthquakes are said to be incompletely kept prior to 1928. In 1928, the United States Coast and Geodetic Survey issued its first annual publication[4] titled "United States Earthquakes."

The early lack of complete records may be attributed to a lack of recording devices, or to a lack of organizations maintaining records. Due to the general unfamiliarity of the populace with earthquakes, many minor earthquakes may have gone unnoticed. On the other hand, some of the minor earthquakes reported in very small areas may be the result of forces other than earth movement. Examples in point are the 1929 earthquake reported from Burrwood, Louisiana, the 1940 tremor reported from Rodessa, Louisiana, and the slight shock of 1941 at Vicksburg, Mississippi. The Coast and Geodetic Survey is, however, reported to have made all possible on-the-ground checks of each reported earthquake.

In general, the Gulf Coastal Plain may be described as an area of relatively low seismicity. The New Madrid-Memphis area in the upper Alluvial Valley of the Mississippi River is the one small part of the Coastal Plain which can be said to be active. The index map (Fig. 1) shows the outline of the New-Madrid-Memphis area and the individual localities of all earthquakes (o) reported in the Coastal Plain outside of that area.

The distribution of reported earthquakes over the Coastal Plain is somewhat irregular. Comparison of Figure 1 with the tectonic map of the United States shows that earthquakes are concentrated on the edge of the Coastal Plain near the Ouachita Mountains in Arkansas. Some of the shocks in this group are known to be located in areas of very sharp gravity anomalies which are underlain by basement rocks at shallow depths. The comparison also shows that the New

---

Survey, and Watson H. Monroe for permission to use material from their publications. A large amount of information on earthquakes was obtained from annual reports of the United States Coast and Geodetic Survey.

Edgar Tobin Aerial Surveys of San Antonio, Texas, kindly supplied several photographs used in this study.

The writer is indebted to H. N. Fisk of the Mississippi River Commission and S. L. Mason for criticism and advice. The writer also wishes to thank the management of the Stanolind Oil and Gas Company, the Pan American Refining Company, the Freeport Sulphur Company, and the Texas Gulf Sulphur Company for permission to publish data included in this paper. Very special thanks are due W. Armstrong Price whose assistance, guidance, encouragement, and advice made this paper possible. References are included as footnotes.

[3] N. M. Fenneman, *Physiography of Western United States*. McGraw-Hill Book Company, New York.

[4] N. H. Heck, "United States Earthquakes," *U. S. Coast and Geodetic Survey* (Washington, D. C.)

Madrid-Memphis area is in close proximity to the Rough Creek fault zone in the southern extremity of the Illinois basin. Some quakes have occurred in the vicinity of the buried Appalachian folds. It therefore seems safe to assume that the reported earthquakes are in some cases the result of extensions of the mountain-building activity from the foregoing three major zones under the Coastal Plain.

The general seismicity of the Coastal Plain seems to decrease progressively away from its inner margin. This fact might be attributed to many factors. The greater thickness of soft unconsolidated sediments may act as a cushion, absorbing some of the shocks. In this regard J. B. Macelwane, S. J.,[5] of the Institute of Geophysical Technology, St. Louis University, St. Louis, Missouri, says that although no special study has been made of relative amplitudes, it is his distinct impression that seismographs at New Orleans on the Mississippi flood plain and coastal plain sediments show a greater relative sensitivity than instruments located on the outcrop of relatively hard formations. This statement denies the idea of absorption. The overburden of sediments may cause the basement rocks to yield along numerous small fractures and a small amount at a time. This type of yielding would be less likely to produce earthquakes than a sudden large relief along a single plane. However, in view of the fact that most earthquakes in this area are believed to originate several miles below the surface, this idea seems unimportant. The degree of competence of the Coastal Plain sediments is believed to decrease progressively away from the inner margin. The less competent sediments probably lend themselves less readily to quake-producing movements.

In the New Madrid-Memphis area one disastrous quake along with twenty-six other major shocks and sixteen separate minor tremors have been recorded. This count should not be considered complete. No effort has been made to list these shocks individually or to show their location on the index map. Details are given in reports of the Coast and Geodetic Survey.[6]

NEW MADRID EARTHQUAKE

Probably the most widely known example of diastrophism which has been recorded in the Gulf Coastal Plain was the New Madrid earthquake at New Madrid, Missouri, in 1811–1812. This earthquake was described by M. L. Fuller.[7]

The area of disturbance of this earthquake is located in the central part of the new Madrid-Memphis area in the vicinity of New Madrid, southeastern Missouri. A series of very violent and very damaging earthquake shocks shook the general area for more than a year, beginning on December 16, 1811, and continu-

[5] J. B. Macelwane, S. J. Personal communication.

[6] See particularly N. H. Heck, *op. cit.*
———, "Earthquake History of the United States Part I, Continental United States," *U. S. Coast and Geod. Survey Spec. Pub. 609* (1938).

[7] M. L. Fuller, "New Madrid Earthqauke of 1811 and 1812," *U. S. Geol. Survey Bull. 494* (1912).

ing until February, 1813. Previous to that time several light shocks had been recorded and many more tremors were noted between 1813 to 1912. This earthquake was felt as far away as Boston, Chicago, New Orleans, and the Atlantic seaboard. Near New Madrid, the quake developed very prominent surface waves and the common quivering and jarring shocks. Some observers reported a deep rumbling noise which seemed to progress from southwest to northeast. L. D. Leet[8] says that "in area affected, continuance of disturbances and severity, the New Madrid earthquake has no equal in the United States history." A description of this earthquake was also made by Lyell,[9] who visited the area 35 years after the disturbance occurred.

Strong motion and visible surface effects covered an area of about 50,000 square miles. Some motion was noted over one million square miles.

The principal features developed as result of the earthquake were as follows.

Many fissures and sand blows were formed. From these fissures and sand blows, large amounts of sand were extruded, accompanied by water and hydrogen sulphide gas. Many landslides occurred, particularly along the Chickasaw Bluffs east of the Mississippi River. Many local slumps took place accompanied by the formation of small fissures along the banks of major streams. Large areas of the land were depressed a few feet and as a result submerged to form lakes. Other smaller areas were uplifted in what Fuller calls "domes," the elevation being limited to a few feet. It may be significant that the uplifted areas are located only a short distance from the areas of large landslides on the Chickasaw Bluffs. Stream courses were changed and lakes were formed. There was a very great amount of damage to buildings and forests in the general area.

One well known surface feature formed as a result of this earthquake is Reelfoot Lake near Tiptonville, Tennessee. The lake was formed as a result of the uplift of the Tiptonville "dome" which was elevated approximately 25 feet with relation to the lake area. Fuller attributes this uplift to a fault originating in the Paleozoic basement. See further discussion under faults F-6.

Fuller[10] states that he believes the New Madrid earthquake to be the result of faulting in the Paleozoic basement. He further suggests that parallel ridges and troughs exhibited in the topography of the area may be due to general compression of the region and may indicate the beginning of a synclinorium. The present writer suggests that many of the features recorded may be due to adjustment by pseudoplastic flow in the water-saturated river alluvium. Such adjustment might be affected by the excessive weight of the Chickasaw Bluffs. It might take form of sedimentary compaction by rearrangement of the grains of the sediments. It is suggested that the earthquake shocks acted as a trigger action to start such adjustment. This idea is supported by Fuller's statement (page 107), that "locally

[8] L. D. Leet, *Practical Seismology and Seismic Prospecting*. Century Earth Science Series (1938).

[9] Charles Lyell, *Principles of Geology*, Vol. 11 (1872), pp. 113–35, 147–54.

[10] M. L. Fuller, *op. cit.*

there was undoubtedly considerable flowage of the substratum of quicksands towards the streams . . . ," that is, toward points where lateral relief was afforded.

Any discussion of earthquakes involves a comparison of the intensity of the various shocks. Numerous scales of intensity have been set up by different authors. While most of them follow a somewhat similar pattern, all vary as to details. In 1935, Chas. F. Richter[11] published his mathematical magnitude scale which has been found useful in California. Until 1931, the United States Coast and Geodetic Survey lists were based on the Rossi-Forel scale, referred to by Dutton.[12] Since 1931, the U. S. C. & G. S. publications have classified earthquakes by the revised Mercalli intensity scale which was proposed by Wood and Neuman.[13] Reference is here also made to the original Mercalli-Cancani scale by Sieberg.[14] For most practical non-instrumental comparisons, the modified Mercalli scale is recommended.

For convenience, the Rossi-Forel and Modified Mercalli (abridged) scales are here reproduced.

Rossi-Forel Scale of Intensities

1. *Microseismic shock.* Recorded by single seismograph or by seismographs of same model, but not by several seismographs of different kinds; shock felt by experienced observer
2. *Extremely feeble shock.* Recorded by several seismographs of different kinds; felt by small number of persons at rest
3. *Very feeble shock.* Felt by several persons at rest; strong enough for direction or duration to be appreciable
4. *Feeble shock.* Felt by persons in motion; disturbance of movable objects, doors, windows; cracking of ceilings
5. *Shock of moderate intensity.* Felt generally by everyone; disturbance of furniture, beds, *et cetera;* ringing of some bells
6. *Fairly strong shock.* General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings
7. *Strong shock.* Overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings
8. *Very strong shock.* Fall of chimneys; crack in walls of buildings
9. *Extremely strong shock.* Partial or total destruction of some buildings
10. *Shock of extreme intensity.* Great disaster; ruins; disturbance of the strata, fissures in ground; rock falls from mountains

Modified Mercalli Intensity Scale of 1931

(Abridged)

I. Not felt except by very few under especially favorable circumstances. (1 Rossi-Forel scale)

II. Felt only by few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (1 to 2 Rossi-Forel scale)

III. Felt noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated. (3 Rossi-Forel scale)

[11] Chas. F. Richter, "An Instrumental Earthquake Magnitude Scale," *Bull. Seismological Soc. America*, Vol. 25, No. 1 (January, 1935), pp. 1–32.

[12] Clarence E. Dutton, *Earthquakes in Light of the New Seismology*, Chap. IX, Intensity. G. P. Putnams' Sons, New York, or John Murray, London (1904).

[13] Harry O. Wood, and Frank Neuman, "Modified Mercalli Intensity Scale of 1931," *Bull. Seismological Soc. America*, Vol. 21 (1931), pp. 277–83.

[14] A. Sieberg, *Erdbenbenkunde*, pp. 102–04. Jena (1923).

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed, walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rocks noticeably. (4 to 5 Fossi-Forel scale)

V. Felt by nearly everyone, many awakened. Some dishes, windows, *et cetera* broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (5 to 6 Rossi-Forel scale)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (6 to 7 Rossi-Forel scale)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (8 Rossi-Forel scale)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars. (8 to 9 Rossi-Forel scale)

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracks conspicuously. Underground pipes broken. (9 Rossi-Forel scale)

X. Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (10 Rossi-Forel scale)

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air

Table I lists the number of earthquakes which are believed to have originated

TABLE I

GULF COASTAL PLAIN EARTHQUAKES BY STATES AND AREAS

1. New Madrid-Memphis area	27 Major	16 Minor	Total 43
2. Alabama		3	
3. Arkansas		6	
4. Georgia		2	
5. Louisiana		5	
6. Mississippi		2	
7. Oklahoma		1	
8. Texas		3	

TABLE II

GULF COASTAL PLAIN EARTHQUAKES
(Exclusive of New Madrid-Memphis Area)

Year	*Number*	*Year*	*Number*
1843	1	1932	1
1872	1	1933	0
1882	1	1934	1
1886	1	1935	0
1891	1	1936	1
1911	1	1937	0
1917	1	1938	1
1918	1	1939	2
1928*	1	1940	1
1929	2	1941	1
1930	2	1942	0
1931	1	1943	0

* First annual report of the U.S. Coast and Geodetic Survey.

in the Gulf Coastal Plain area by states. Arkansas, which has a small area in the Gulf Coastal Plain, has the largest number of shocks outside the New Madrid vicinity. Table II lists the Coastal Plain earthquakes exclusive of the New Madrid-Memphis area, by years. From the published records of the Coast and

TABLE III

GULF COASTAL PLAIN EARTHQUAKES

(Exclusive New Madrid-Memphis Area)

1843, Feb. 14 and 15—Morgan City, La. 30.0 N., 91.0 W. Light shock

1872, June 17—Milledgeville, Ga., 33.1 N., 83.3 W. Sharp shock; brick buildings jarred, windows rattled

1882, April—Morgan City, La., 30.0 N., 91.0 W. Light shock

1886, Feb. 4 and 13—Sumpter and Morengo counties, Ala. 32.8 N., 88.0 W. Felt on both sides of Tombigbee River for 32 miles from Moscow. At that place, the earth seemed to move

1891, Jan. 8—Rusk, Tex., 31.7 N., 95.2 W. Listed without details

1911, Mar. 31—Rison and Warren, Ark., 33.8 N., 92.2 W. Houses swayed, loose articles thrown from shelves. Felt throughout southeast Arkansas, northeast Louisiana. Area half-moon-shaped. Reid considered the area disturbed to be result of soft Mississippi River alluvial deposits in which the shock was more strongly felt then elsewhere. This contradicts the idea of soft sediments absorbing waves. This earthquake is located on a very sharp gravity anomaly under which basement rocks were found at a shallow depth

1917, June 29—Greensboro, Ala. 32.7 N., 87.5 W. Force 5 Rossi-Forel

1918, Oct. 4—20-30 miles SE. of Little Rock, Ark. 34.7 N., 92.3 W. Felt at Black Rock 120 miles northeast and at Memphis. Felt over 30,000 square miles

1928, May 23—05:15—Valdosta, Ga., 30.8 N., 83.3 W. Apparently seismic tremor, some thought there was another a few minutes later. Large meteor passed over about 25 minutes before

1929, June 13—08:44—Mobile, Ala., 30.7 N., 88.0 W. Felt by very few. Swaying in east-west directions

1929, June 28—11:00—Burrwood, La., 29.0 N., 89.4 W. Windows rattled

1930, Oct. 19—06:17—Morgan City, La., 30.0 N., 91.0 W. Felt over 15,000 square miles. Maximum intensity VII. Small objects overturned, windows rattled, rapid motion for 30 seconds. Ground heaved gently

1930, Nov. 16—06:30—Malvern, Ark., 34.3 N., 92.7 W. Residents rudely awakened, slight damage to house. Felt at Huskey Creek, Perla, Damascus, and Leola

1931, Dec. 16—Charleston, Miss., 34.0 N., 89.7 W. Walls and foundations cracked, some chimneys thrown down. Plaster thrown down at Belzoni

1932, Apr. 9—Mexia and Wortham, Tex., 31.7 N., 96.4 W. Loose bricks were thrown down and plaster cracked

1934, Apr. 11—Lamar County, Tex., 33.9 N., 95.5 W. Strong at Paris, Tex., and Hugo, Okla. No damage reported

1936, Mar. 14—11:20—Intensity V at Valliant and Wright City, Okla. Weak shock over most of southeast Oklahoma

1938, Apr. 25—23:42—southeast of Little Rock, Ark., just outside of Fendley. Felt slightly over small area

1939, June 1—01:30—DeQueen, Ark. Intensity IV M. Other reports from Antlers, Ark., Holdenville, Tulsa, and Oklahoma City, Okla.

1939, June 19—15:43—Arkadelphia, Ark. Intensity V. Plaster cracked in some buildings. Also felt at Crossett, Dumas, El Dorado, Fordyce, Hot Springs, Pine Bluff, and Prescott

1940, Dec. 2—10:16—Rodessa, La., Intensity 4. Dishes shaken from shelves. Not felt in near-by towns

1941, June 28—12:30—Vicksburg, Miss. Slight shock

Geodetic Survey and from other sources which were available, a list of earthquakes which are believed to have originated within the boundaries of the Gulf Coastal Plain has been compiled Table III. In this list, which excludes quakes from the New Madrid-Memphis area, intensities, and latitude and longitude are given where possible.

GENERAL DISCUSSION—EARTHQUAKES

The fact that so many earthquakes have been recorded in historic time indicates that during geologic time the number of earthquakes must have been very large. While the Gulf Coastal Plain is classed an area of low seismicity, earthquakes have occurred at widely scattered points and they may be expected to continue.

FISSURING AND FAULTING

Very interesting records of fissuring and faulting have come to the writer's attention, so many that he has not investigated all. A few of the seemingly more important are included here. Reference is not made to merely dry-weather cracks, which commonly appear during dry seasons in the western part of the Coastal Plain. The Laura Thompson topographic graben,[15] Bee County, Texas, was studied by use of aerial photos for evidence of historic diastrophism. None was noted. This item is more fully discussed by Price.[16]

FISSURES IN NUECES COUNTY, TEXAS F-1

W. Armstrong Price[17] reports that during an exceptional period of drought in 1918 deep fissures formed in the Beaumont clay prairie in Nueces County, Texas. The fissures reappeared for several dry seasons thereafter and were much deeper and wider than normal dry-weather cracks. One such fissure was located at the Richard King Ranch house in Section 9 of the Richard King Farm tracts on the south bank of Agua Dulce Creek, about 5 miles north of the village of Agua Dulce in the extreme west part of Nueces County. From this fissure a small amount of gas escaped under low pressure and was burned from time to time. It may be significant that this fissure was located above the north flank of an anticline with gas-bearing strata at a depth of approximately 4,000 feet.

In the same general area F-2 at about the same time, in the vicinity of Agua Dulce oil field, a farmer reported to Price that he saw a fissure in the clay bank of Pintas Creek. The farmer reported that gas, which was escaping from the fissure under low pressure, became ignited by a prairie fire and as the gas burned, the flame flickered back and forth along the crack. The exact location of this last fissure is not definitely known. Price believes that it must have been located in the vicinity of the present oil and gas development southeast of the original gas field. In the field, a mile or so from the creek, gas has been produced from reservoirs at depths as shallow as 1,900 feet.

Price believes that these fissures are definitely surface soil features and that

[15] W. Armstrong Price, "Role of Diastrophism in the Topography of Corpus Christi Area, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 8 (August, 1933), p. 907. *Ibid.*, *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol., pp. 205–50.

[16] W. Armstrong Price, "Quaternary Diastrophic Activity on Coastal Plain of Western Gulf of Mexico." Read before the Association at Chicago, April 3, 1946.

[17] W. Armstrong Price, personal communication.

they were open only in very dry seasons. The fact that gas was escaping from them makes them important.

As a possible explanation, Price suggests (1) that the surface fissures may have cut shallow sands which were lightly charged with gas through the fault planes from the productive zones below. In this instance, 400- to 500-foot water wells in the vicinity may have aided the charging process by allowing passage of the gas through the well bore. (2) The observed cracks may have traversed shallow deposits of organic muds from which marsh gas was released. A third explanation appears to be possible. The observed cracks may represent the surface expression of fault planes which intersect the gas reservoirs in the producing areas. The gas may have escaped along these fault planes. Such surface expressions of faults might remain as zones of weakness but stand open only at periods of exceptionally low water table.

FISSURES IN LAVACA COUNTY, TEXAS F-3

Bell and Brill[18] reported in 1937 the presence of a fissure in Lavaca County which they interpret as being an active fault. The fault was first given scientific study by Raymond H. Goodrich of Houston who reports that the landowner, E. Pohl, said the fissure had been open more than 41 years. Bell and Brill report that it is known to have been open for the past 20 years. The fissure was located on the Pohl ranch in the Patrick Bradley Survey of eastern Lavaca County, Texas. It was 4 to 6 inches wide, and could be traced on the surface for more than 2,000 feet. The strike was approximately N. 60° E. There was no evidence of dip or amount of displacement except that at one point a scarp of about 3 inches was noticeable.

At this locality, the outcrop of Willis formation (Pliocene-Pleistocene) is covered by a dense growth of post oaks. Where the fissure encountered a tree, the tree was split or broken apart. In one tree an old scar about one inch wide and extending a foot above the ground had healed and a new split approximately $\frac{1}{8}$ inch wide had recently formed. This example is pictured in the Bell-Brill paper. Those who have studied this phenomenon on the ground agree that this fissure represents the surface expression of recently active fault.

ACTIVE FAULTS IN LEE COUNTY, TEXAS F-4

A. W. Weeks[19] (1945) reports that there is evidence of a very recent movement along fault scarps in Lee County, Texas. He states "That some movement continued to the present is evidenced by the so-called Breastworks at the surface trace of faults in the Mexia zone in the northern part of Lee County in the general vicinity of Lexington, where in places the upthrown side of the fault stands

[18] Douglas E. Bell and V. A. Brill, "Active Faulting in Lavaca County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 1 (January, 1938), pp. 104–06.

[19] A. W. Weeks, "Balcones, Luling, and Mexia Fault Zones in Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 12 (December, 1945), p. 1733.

a few feet higher at the surface than the downthrown side." This historic movement is corroborated by Glen Stewart[20] who also worked in this area.

FAULT AT VACHERIE, LOUISIANA F-5

In the vicinity of Vacherie, Louisiana, on the south bank of the Mississippi River about 50 miles west of New Orleans, a surface fissure of a very striking type formed in 1943. After growing for 3 days, the fisure reached a total length of approximately one mile and stood open near the center. Its maximum displacement in the central part was reported to be several inches. The strike of this fissure-fault was approximately N. 30° W., with the west side downthrown. An investigation of this feature was made by H. N. Fisk, consultant for the Mississippi River Commission. His findings are included in his final report[21] to the commission. The presence of the fault was substantiated by subsurface borings which indicated 3½ feet of displacement.

It may be significant that this surface fault is located above the southeast flank of the Hester salt dome. Fisk says a slight earthquake was recorded in the vicinity; however, K. A. Maring, S. J., of Loyola University at New Orleans, reports that no earthquake was recorded by the university seismograph approximately 50 miles away near the date on which the fissure formed. It is reported that this fault had the appearance of a subsidence feature, and that most surface traces of it have since disappeared.

FAULT NEAR TIPTONVILLE, TENNESSEE F-6

Near Tiptonville, Tennessee, during the period of the New Madrid earthquake, an area called the Tiptonville "Dome" was uplifted approximately 25 feet. This uplift obstructed natural drainage and formed Reelfoot Lake. The uplifted area, which is elongate north and south, is bounded on the east by a down-to-the-east fault with several feet of displacement. This fault was first mentioned by M. L. Fuller[22] and attributed to movement originating in the Paleozoic basement rocks.

FRACTURE PATTERN OF CENTRAL COASTAL PLAIN, F-7

In another phase of the investigation of the Mississippi River Alluvial Valley, Fisk describes in considerable detail a fracture pattern mapped for the entire region. Briefly, the pattern of fracturing shows two closely knit sets of intersecting zones of weakness. One set strikes northeast and the other set strikes northwest. The zones were determined principally from study of the aerial photographs, where they appear in the displacement of stream courses, ponding of drainage, *et cetera*. Some of the fractures have been checked by borings and sub-

[20] Glen Stewart, personal communication.

[21] H. N. Fisk, "Geological Investigation—Alluvial Valley—Lower Mississippi River." Mississippi River Commission, Vicksburg, Mississippi (December, 1944).

[22] M. L. Fuller, *op. cit.*

surface displacement has been measured. The cross sections of the Alluvial Valley prepared by Fisk show a series of faults in the alluvial fill which form a complex graben. In some cases the lowest block centers over the area of deepest fill near the middle of the valley and the other fault blocks step up on each side till the highest outside block is reached. To the writer, this graben system definitely has the appearance of subsidence and, it is thought may be due to unequal compaction.

In the course of his investigations, Fisk noted a close relation between the fracture pattern and the form of the walls of the Alluvial Valley. Relation was also established between the fractures and the location of numerous river valleys. Preliminary investigations show that some crevasses through the artificial levees of the Mississippi occur in areas where principal fracture zones cross the valley. Such relations suggest a possible cause for crevassing which has not as yet been proven.

In studying Fisk's writings on the subject, the impression is gained that this fracture pattern is tectonic and is in some way related to the general diastrophism of the region as a whole. Comparison of this fracture pattern with the Tectonic Map of the United States shows that the northeast-trending fractures roughly parallel the trend of the Appalachian folds. Also that the northwest-trending fractures roughly parallel the regional strike of the Coastal Plain sediments in Mississippi.

There is also a rough parallelism between the northeast-striking faults and the outcrop of the older formations of the Coastal Plain in Arkansas and Missouri. These relations may or may not be significant.

The Central Gulf Coast fracture pattern may be the result of the general gulfward subsidence of all Coastal Plain sediments. This subsidence may very well be activated in part by microseisms which are believed to be passing through the earth's crust almost constantly. The strike of the fractures in the Central Gulf Coastal Plain is probably influenced by the form of the Mississippi structural trough.

FISSURES IN MISSISSIPPI F-8

In Rankin County, Mississippi, near the town of Pelahatchee, cracks or fissures of a special type were reported by Watson H. Monroe.[23] The fissures were located in the SE. $\frac{1}{4}$ of Sec. 30, T. 6 N., R. 5 E., about one mile northwest of Pelahatchee on the slope of Ware Hill. The outcrop at this point is Yazoo clay which, when weathered, becomes very plastic. In dry weather, cracks 3 inches wide and several feet deep form in this clay. In the case of the Ware Hill cracks, the downslope side was marked by a small ridge 2 to 3 feet wide and 1 to $1\frac{1}{2}$ feet high, with its steeper slope on the side next to the crack. This feature gives the cracks the appearance of faults with the ridge forming the upthrown block. One large crack

[23] Watson H. Monroe, "Earth Cracks in Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 2 (February, 1932), pp. 214 and 215. *Ibid.* (abstract), *Pan Amer. Geol.*, Vol. 57, No. 4 (May, 1932), p. 308.

was 6 inches wide, more than 3 feet deep, and 160 feet long. The paralleling ridge was 3 feet wide and 1½ feet high. In some places, trees had been lifted and tilted with some roots pulled out of the ground. Similar cracks had been noted in this area for the 5 years previous to Monroe's visit. These cracks remained open even in wet weather.

No record of any earthquake was made in the area so this is not a likely explanation. In view of the fact that the Yazoo clay is very much subject to swelling in wet weather and cracking in dry weather, Monroe attributes the fissures to soil creep.

GENERAL DISCUSSION—FAULTING

Evidence of faulting in several forms has been described from a wide range of areas. Most of these faults appeared to be slump features which emphasizes the importance of the force of gravity. In each case where control was afforded, the throw of the fault increased with depth. Increasing throw with depth is generally true of the prehistoric faults of the Coastal Plain as well.

It has been said that the decreased throw in the younger, shallower beds indicates that the faults grew intermittently during deposition. This idea would certainly appear to be true in many cases—however, the writer suggests that the change in throw of the fault may be due in part to differential compaction in the sediments on the two sides of the break.

Some of the Coastal Plain faults probably form as a result of upthrusting masses. Let us assume for the moment that through one cause or another a large block fault occurs in the basement rocks, which are overlain by several thousand feet of Coastal Plain sediments. Certainly a continuation of the basement fault would be developed in the sediments above. The beds in the upthrust block would be subjected to great vertical compressional stresses and the whole area would probably be shaken by the resulting earthquake. Undoubtedly a great amount of compaction would take place in the upthrust sediments probably by grain rearrangement and the amount would certainly decrease upward, away from the source of the compressional forces and the earthquake shocks.

Evidence of a similar sort of thing is found at the Hastings oil field, Brazoria County, Texas. The structure here is believed to be the result of upthrusting of a deep-seated salt mass. Electric logs were run in nearly every well in this field and by their use a fairly complete picture of the structure can be reconstructed. At a depth of approximately 6,000 feet one major fault which has a throw of about 700 feet dominates the structural picture. This fault which is believed to be the result of the upward movement of the salt plug has the form of a normal fault. In attitude and direction of displacement it has all the characteristics of the many other normal extensional faults in this structure which are believed to have been formed by elongation of the section over the uplift.

The electric logs through the sands in the highest upthrown fault block show that these sands have a noticeably reduced self potential, compared with the

same sands in other parts of the field. This reduction in self potential is believed to indicate reduced porosity. Also in the upthrown block the sediments are noticeably thinner than elsewhere. None of the sand section appears to be missing. It therefore becomes logical to conclude that the sediments in the upthrust block were compacted by means of grain rearrangement as a result of the upthrusting salt mass. To complete the simile the major fault at Hastings with a 700-foot throw at a depth of 6,000 feet dies out completely before reaching a depth of 3,000 feet. Also, there is little, if any, surface expression of the structure, which at a depth of 6,000 feet is uplifted approximately 1,500 feet. The decreased fault throw and lack of surface relief are common occurrences on deep-seated salt-dome fields of the Gulf Coast. These two features may be partly caused by smoothing over by late sedimentation but the writer believes that differential compaction consumes a large amount of the uplift.

This discussion serves to emphasize the importance of compaction in the history of Gulf Coast structures. Further, it leads to the conclusion that, in a normal thickness (10,000–20,000 feet) of soft Coastal Plain sediments, any fault in the basement rocks would need to be of stupendous throw in order to be reflected by displacement at the surface. It therefore follows that, although some surface faults in this region may be directly related to movement in the basement complex, the number of this type is probably small.

Differential compaction may be the immediate cause of such subsidence faults as that at Vacherie, Louisiana. In such cases microseisms may aid in the movement.

In a later part of this paper (Local Subsidence and Uplift S-2 and S-5) concentric slump faults are described, encircling recent slump depressions at Sour Lake and Boling domes, Texas. The similarity between these slump features and the series of down-to-coast faults, which partly encircle the Gulf of Mexico, is very striking. It is here suggested that the two sets of features might be a result of similar forces.

REGIONAL WARPING

The evidence for this type of diastrophism is probably the most difficult to evaluate by historic records. However, a few items have been described which it seems may best be placed in this category.

ELEVATION OF COAST LINE AT ST. MARKS, FLORIDA W-1

The Southeastern Geological Society reported in its bulletin on its Third Annual Field Trip that a part of the western Florida coast line in the vicinity of St. Marks shows evidence of having risen approximately $1\frac{1}{2}$ feet in 50 years. This elevation was reported by T. Wayland Vaughan[24] in 1902.

[24] T. Wayland Vaughan, "Evidence of Recent Elevation of the Gulf Coast along Westward Extension of Florida," *Science* (News Series), Vol. XVI (September 26, 1902), p. 514.

HISTORICAL SHORE-LINE CHANGES ON MISSISSIPPI DELTA W-2

A comparison made by W. Armstrong Price[25] between modern maps and the early Spanish and French maps of the coast of Louisiana collected by Donald C. Barton, showed a shoreline retreat of several miles along considerable stretches of the Mississippi delta. The area especially noted was the north coast of Breton Sound (east side of the delta) where the early mapping was done in best detail and the retreat was in excess of the evident limits of error of that part of the map.

Examinations of the bluffs of Chandeleur Sound by Russell[26] (1936) shows that erosion is only partly responsible for this retreat. Russell points out that a difference in interpretation of what is marsh and what is water might account for a part of the changes. Russell cites what he considers definite evidence of submergence in Recent if not Historic time. Indian mounds and the natural levees of a former Mississippi River distributary channel were traced by borings under the adjacent marsh. These features indicate that the east side of the Mississippi delta has been tilted toward the east. The tilting occurred after the deposition of a great load of sediment by the distributary channel and is directly attributed to that load.

Russell[27] in 1942 published a report on "flotant," a swamp accumulation of organic material which rapidly encroaches on bodies of fresh and slightly brackish water. It does not, however, thrive in saline water and can not stand the pressure of even small waves, therefore, it does not effect the outer coast line.

Price[28] pointed out that shoreline changes similar to the Louisiana type have occurred at other places along the Gulf Coast, for example, near the mouth of the Rio Grande, which appeared to be due to adjustments other than submergence. It therefore becomes apparent that before any shoreline change can be attributed with certainty to diastrophism a very careful examination of all factors should be made.

EROSION OF EASTERN TEXAS COAST W-3

A State Highway follows close to the beach from Galveston, Texas, eastward to the Louisiana line. Some parts of this highway nearest the beach have had to be relocated farther inland several times due to the erosion of the beach by wave action. This lateral erosion as measured by engineering surveys has exceeded 400 feet during historic time in the vicinity of High Island, Texas. It is suggested that this erosion may be due to the Quaternary and Recent submergence along

[25] W. Armstrong Price, personal communication.

[26] Richard Joel Russell, "Deltas of the Mississippi River" (abstract), *Pan-Amer. Geol.*, Vol. 65, No. 3 (April, 1936), pp. 236–37.
———, "Lower Mississippi River Delta in Reports on Geology of Plaquemines and St. Bernard Parishes, Louisiana," *Louisiana Dept. Conservation Geol. Bull. 8* (November, 1936).

[27] Richard Joel Russell, "Flotant," *Geographical Review*, Vol. 32, No. 1 (January, 1942), pp. 74–78.

[28] W. A. Price, personal communication.

this coast which has been established by Price.[29] This submergence may be continuing at present. Johnson[30] (1919) refers to both the Atlantic and Gulf Coastal Plains as having shore lines of emergence complicated by recent slight submergence. He cites cases of wave-cut bluffs in the Coastal Plain in North Carolina and Florida and suggests they may be due to submergence.

Obviously ocean waves are constantly cutting away at all coast lines. Whether the shore is receding landward or proceeding seaward depends on many factors, a few of which are here listed.

1. The amount of energy present in the ocean waves
2. The present rate and amount of recent subsidence
3. The elevation of the landmass subsiding and its resistance to erosion
4. The present rate and amount of recent elevation
5. The slope and nature of the ocean floor being elevated
6. The present rate of out-building by deposition

In the case of erosion described in the Texas Coast a positive answer should be withheld pending a detailed investigation of all the facts.

WATER MAIN BREAKS AT WACO, TEXAS W-4

The City of Waco, located on the Balcones fault system, central Texas,has experienced unusual difficulty with breaking water and sewer lines. In one instance, Frank Bryan[31] became convinced that the breaks were caused by a movement along a fault; however, no visible displacement was reported at the time.

Bryan describes a 42-inch cast-iron water main with rigid, lead-sealed joints buried 20 feet underground in a broad flat stretch of land north of Waco. This water main was broken 36 times during an 18-month period at a point within 300 feet of the place where the pipe crosses a member of the Balcones fault system. This fault, according to Bryan, is well established by surface and well control farther north. He states that these repeated breaks were undoubtedly due to movement along the fault plane; however, he cites no other evidence of historic fault displacement. That there are two sides to every question is evidenced by the fact that the City of Waco collected heavy damages from the company who manufactured the pipe, for faulty workmanship. This fact should not necessarily be considered scientific evidence. Bryan mentioned the fact that the Valentine, Texas, earthquake[32] was felt in Waco at about the beginning of the 18-month period mentioned. The epicenter of this quake, was located, however, in extreme West Texas and it seems doubtful that the slight intensity felt at Waco would be sufficient to break water mains. It is possible that the reported breaks may be due

[29] W. Armstrong Price, *op. cit.*

[30] Douglas W. Johnson, *Shore Processes and Shore Line Development.* John Wiley and Sons (1919).

[31] Frank Bryan, "Recent Movements on a Fault of the Balcones System, McLennan County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (April, 1933), pp. 439–42.

[32] E. H. Sellards, "Texas Earthquake of August 16, 1931" (abstract), *Bull. Geol. Soc. America*, Vol. 43, No. 1 (March, 1932), pp. 146 and 147.

to extensional forces such as warping active in the vicinity of the fault which may later produce displacement along the fault plane.

GENERAL DISCUSSION—WARPING

Price[33] points out that Corpus Christi Bay and Galveston Bay are each believed to be structural basins formed in Quaternary or Recent time. Price also cites evidence that the western Louisiana Coast has been elevated and Russell[34] cites evidence that the east side of the Mississippi delta has subsided. Again there is evidence that the west part of Florida has been elevated. Earthquakes produce surface waves; the writer asks, could the aforementioned warps be the result of geologic waves in the earth's crust, with wave length of 50–150 miles, amplitudes of 50 feet, and a geologically slow rate of transmission?

The downwarps at the mouths of the major rivers may be due to load deposited there but the ancient counterparts of these rivers probably flowed into the sea at widely different points and, if the sediment a river deposits in the delta warps the area downward, why should a river ever abandon the general emptying vicinity of its first choice? It seems to the writer that the location of river mouths may be controlled by local downwarping rather than the downwarping being controlled by the river.

LOCAL SUBSIDENCE AND UPLIFT

A number of instances of local subsidence are included in this chapter. Most of these are attributed to the works of man rather than to natural causes; however, under the broad definition of diastrophism, these should be included. These local subsidence features serve better than any other evidence of diastrophism to demonstrate the importance of the force of gravity in Gulf Coast earth movements.

SUBSIDENCE AT GOOSE CREEK, TEXAS S-1

A relatively large area of local subsidence was reported from Goose Creek, on the eastern edge of Harris County and on the northern margin of Galveston Bay, Texas. This area corresponds approximately with position of the Goose Creek oil field which is generally believed to be a deep-seated salt-dome structure, although no salt was logged in the deepest well drilled to 6967 feet.

The slump occurred in 1918. An oval area approximately $2\frac{1}{2}$ miles long, east and west, by $1\frac{1}{2}$ miles wide north and south, sank approximately 3 feet at the center.

The subsidence was first reported by H. E. Minor[35] in 1925. He attributed the slump to removal of oil, gas and salt water from the pay sands at 1,000 to 4,600 feet which, according to his idea, would allow compaction of the sands and shales

[33] W. Armstrong Price, *op. cit.*

[34] Richard Joel Russell, *op. cit.*

[35] H. E. Minor, "The Goose Creek Oil Field, Harris County, Texas," *Bull. Amer. Assoc. Petrol.*, Vol. 9 (1925), pp. 286–87.

by rearrangement of grains. Here again we see compaction and gravity in action.

In 1926, Pratt and Johnson[36] described the evidence of Goose Creek subsidence in more detail. They agreed with Minor in all essentials. Again in 1930, Sellards[37] described essentially the same features.

Evidence for this slump was found in slump cracks, submergence, and altered ground levels. One persistent crack downthrown on the south passed through the north edge of the village of Pelly. It could be traced for 500 to 600 feet and exhibited a maximum throw of approximately 16 inches. Similar slump cracks downthrown toward the north were reported on the north bank of Hogg Island on the south edge of the oil field.

Carefully run ground levels of the entire area indicated a subsidence near the center of 2.7 feet. The subsidence was also indicated by the submergence of what was formerly known as Gaillard Peninsula and by the drowining of swampy lands in the bed of Goose Creek and adjacent areas.

All the later writers agreed with Minor that the subsidence was probably due to withdrawal of tens of millions of barrels of fluid and gas from the producing reservoirs found at shallow depths. No significant amount of sand was produced.

In view of the fact that no well had encountered salt on the dome, little credence was given to the idea of a solution cavity in the salt mass. As a result of all the testimony that the slump was caused by the works of man and not an act of God, the State of Texas lost a suit to recover minerals produced from the land which was submerged by the sinking.

SUBSIDENCE AT SOUR LAKE, TEXAS S-2

On the Sour Lake dome in southern Hardin County, Texas, E. H. Sellards[38] reports that a very large depression developed. The depression began sinking early on the morning of October 9, 1929, and by mid-day had formed a bowl-shaped hole approximately 1,400 feet in circumference and 70 feet deep. From that time on, lateral movement of the soil toward the center tended to reduce the depth and enlarge the area affected. By nightfall, the depression was 2,000 feet in diameter and approximately 40 feet deep. A smaller subsidiary depression formed near the north edge of the original sink on October 12.

The sunken area (Fig. 2) is located approximately 1,500 feet northeast of the crest of the dome at which point domal material is found within approximately 900 feet of the surface. Numerous oil wells in the vicinity of the sink were damaged and storage tanks were made useless by submergence in the resulting lake.

Sellards estimated the total earth quantity affected at approximately 100,000 cubic yards. The sinking was attributed to the formation of a cavity by solution of salt and the resultant collapse of the overlying cap rock. The dissolved salt is

[36] Pratt and Johnson, "Local Subsidence of the Goose Creek Oil Field," *Jour. Geol.*, Vol. 34 (1926), pp. 578–90.

[37] E. H. Sellards, "Subsidence in Gulf Coastal Plain Salt Domes," *Texas Univ. Bull. 3001* (1930), pp. 9–36.

[38] E. H. Sellards, "Ground Subsidence at Sour Lake, Texas," *Mining and Metallurgy*, Vol. 11, No. 284 (August, 1930), pp. 337–80.

believed to have been brought to the surface in the water produced from the oil wells. The amount of salt thus removed is impossible to estimate.

This depression was recently examined in the field. It is still very much in evidence although somewhat subdued in relief. The bottom of the depression is

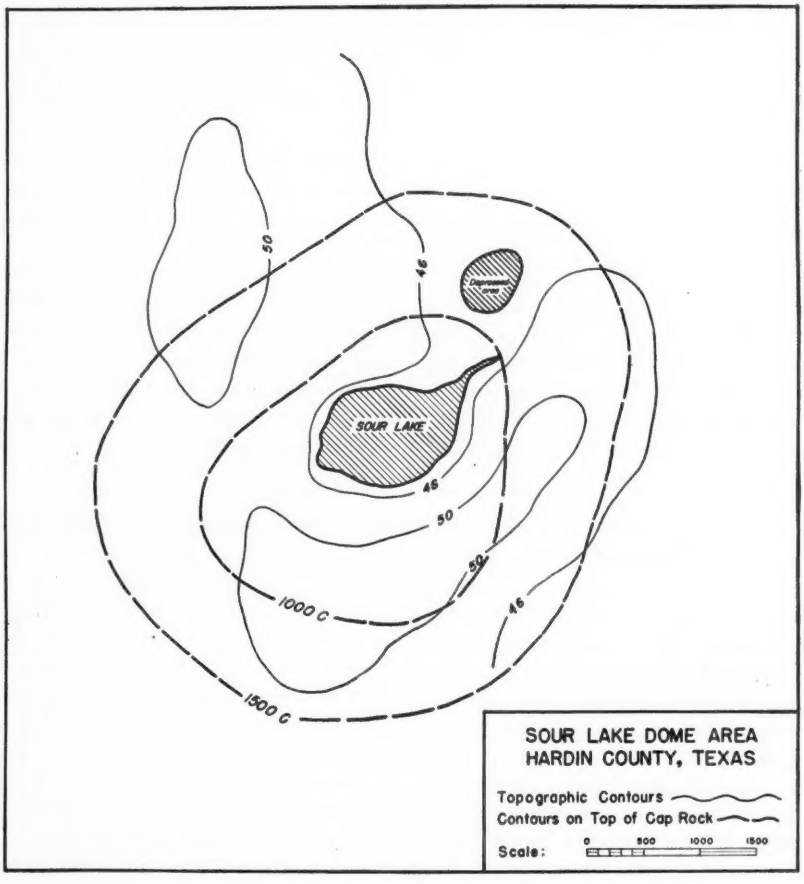


FIG. 2

now a salt-water storage lake estimated at 4 to 5 feet deep. Figure 2 shows the relation of the depressed area to the dome and the old original Sour Lake. Sour Lake itself which was an open lake about 20 years ago is now a marshy area with young pine trees growing scattered through it. The relations shown on Figure 2 suggest that the 1929 subsidence may have been due to the same natural solution

which caused Sour Lake in prehistoric time. The process may have been hastened by removal of salt water through producing oil wells. Many other lakes and depressions at present found above salt plugs may have been formed by the same natural causes.

LARGE SLUMP IN MISSISSIPPI

R. J. Russell[39] reported a large slump which occurred about 2 miles south of Fort Adams, Mississippi, in October, 1933. The slump occurred during dry weather and at low-river stage. Ninety-seven acres were affected on the west slope of a bluff approximately 270 feet high. The bluff is composed of the unconsolidated clay, sand, and silt of natural levee deposits usually referred to in this locality as loess. These deposits and other more or less consolidated Tertiary sediments extend at about the same elevation for a long way east. Toward the west, the bluff faces the low-elevation, deep, very unconsolidated Mississippi River Alluvial Valley.

The slump produced the ordinary concentric scar, and in the block itself a highly complicated system of horst and graben faulting. The striking thing about this occurrence is the author's description of the movement of the material forming the slump block "downward and outward into the alluvium." This, then, is an example which illustrates that the force of gravity, coupled with unequal lateral support, can produce horizontal displacement, the formation of complicated structural features and at some points even local uplift.

SUBSIDENCE AT TEXAS CITY, TEXAS S-4

John M. Vetter[40] has described to the writer subsidence which is taking place at the Pan American Refining Company's Texas City refinery. The refinery was put into operation in 1933 and up until 1939 no evidence of sinking was noted from the annual check of bench marks. The records on exact elevations within the refinery site are incomplete for the war years; however, it is reported that the first evidence of subsidence was noticed in 1940. In May, 1945, a complete and very detailed survey of elevations was made in the refinery area. This survey showed that an irregular area comprising about 40 acres in the midst of the greatest concentration of refinery structures had subsided a maximum of about $1\frac{1}{2}$ feet. A second detailed survey taken in November, 1945, showed a maximum of $\frac{1}{2}$ foot additional subsidence during that 6-month period, and a third survey made in February, 1946, showed a maximum additional settling of less than $\frac{1}{10}$ foot at any given point during the preceding 4 months. The total maximum subsidence was thus 2.11 feet. To date no damage has resulted to surface structure at the refinery but the gravity drainage system has been disrupted to some extent and in some cases sewer lines have actually been broken.

[39] Richard Joel Russell, "Slump near Fort Adams, Mississippi" (abstract), *Proc. Geol. Soc. America, 1934* (June, 1935), p. 104.

[40] John M. Vetter, personal communication.

It was first thought that the subsidence might be due to overloading of the clay foundation. Stabilization tests made previous to the construction of the refinery seem to have effectively eliminated this possibility.

N. A. Rose[41] has made a thorough investigation of the causes and is convinced that this subsidence is related to water withdrawals, from shallow-water sands.

The theory governing subsidence over areas of heavy fluid withdrawals involves compaction of the shales. The shales are believed to be more porous than the sands and more highly water-saturated. Lowering the water table lowers the hydrostatic pressure in sands and in turn allows water to be squeezed from the shales which then become more compact. Grain rearrangement may play a part in this compaction. Any movement, however small, is probably transmitted to the sands, in the course of which they too may become compacted by grain rearrangement.

The Pan American Refining Company is watching this area of subsidence very closely and more detailed information will undoubtedly be available in the future. This illustration was described in detail because of its economic importance to geologists and also because it serves to illustrate the importance of the force of gravity on movements which involve the unconsolidated Coastal Plain sediments.

An instance very much like the preceding was reported by Weaver[42] in 1943, in the vicinity of Delano on the Tulane-Kern County line in California. The subsidence described previously at Goose Creek, Texas, is believed to be of the same nature but involving oil, gas, and salt-water withdrawals. Similar subsidence has also been reported in the Lake Maracaibo district, Venezuela.

SUBSIDENCE ASSOCIATED WITH SULPHUR EXTRACTIONS S-5

Nearly every area where sulphur is mined by the Frasch process in the Gulf Coast sooner or later shows some evidence of subsidence. The cap-rock material commonly limestone, in which the sulphur is found generally has considerable porosity when first drilled. The removal of quantities of sulphur from this mass increases the porosity. The structure of the cap rock is, so weakened by this process that it is incapable of supporting the overburden of unconsolidated sediments. As a result, the limestone is fractured, it subsides, and surface slump results. This fracturing, which amounts almost to crushing, under loads of a few hundred feet of overburden gives some idea of what may go on at depth under thousands of feet of sediment when strains are applied or local relief is afforded. This slumping and filling in of mined-out areas is helpful to mining operations because of the fact that it confines the mine water to the unmined formations. It does, however, create some problems at the surface.

Probably the most striking example of post-sulphur extraction subsidence is

[41] N. A. Rose, personal communication.

[42] Paul Weaver, "The Geophysicist as a Forecaster," *Geophysics*, Vol. 8, No. 3 (July, 1943).

described at Sulphur dome, Calcasieu Parish,[43] Louisiana (S-5). In this case the sulphur-bearing cap rock was originally encountered at approximately 400 feet. The maximum subsidence on this dome is calculated at approximately 130 feet. The depth of the depression could not be measured directly due to the fact that it was periodically filled with dredged material.

Another good example of this type is described by Wolf[44] at Gulf (Big Hill)

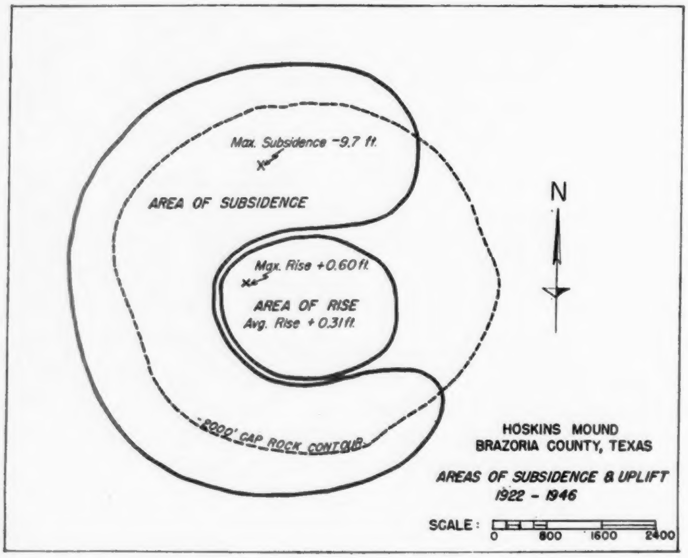


FIG. 3

Dome (S-5) on the coast of Matagorda County, Texas. This dome originally appeared as a mound which reached a maximum height of 37 feet above sea-level. The sulphur removal caused subsidence in the order of 40 feet which formed a lake on top of the mound.

Wolf[45] has stated that mining operations of the Texas Gulf Sulphur Company at Newgulf on Boling Dome (S-5), Wharton County, are now causing active subsidence. The company is following this subsidnece very closely with accurately contoured records of its progress. Small areas on this dome have already subsided a little more than 20 feet. Wolf states that in the vicinity of the depressions which

[43] P. K. Kelley, "The Sulphur Salt Dome, Louisiana," *Geology of Salt Dome Oil Fields*, Amer. Assoc. Petrol. Geol. (1926), pp. 452–69.

[44] Albert G. Wolf, "Big Hill Salt Dome, Matagorda County, Texas," *ibid.*, pp. 691–717.

[45] Albert Wolf, personal communication.

are forming imperfect circular faults sometimes develop at the ground surface downthrown toward the depression. In a previous chapter these faults have been compared with regional faults of the Gulf Coast.

C. M. Sampson[46] reports that subsidence is now occurring around the flanks of Hoskins Mound (Fig. 3, S-5), Brazoria County, Texas, which is being mined at the present time. The maximum subsidence in this instance is in the order of 9 feet. Sampson further reports that 100 acres of area in the central part of this dome has risen a maximum of 0.6 foot in the last 23 years. This rise is indicated by careful level measurements. On this dome the central and eastern parts of the cap rock are largely barren and have not been mined. An excellent description of this dome is reported by Archer H. Marx.[47]

This rise at Hoskins Mound could, of course, be attributed to upward movement of the salt core. Sampson points out however, that only 100 acres of the 600-acre dome are rising. This could be the beginning of a salt spine such as that which adorns Anse La Butte Dome, St. Martin Parish, Louisiana. Sampson points out also tha the entire cap-rock mass, in places more than 200 feet thick, has been heated to approximately 300° F. and that this temperature is maintained by circulating superheated water, but expansion of this limestone would account for only about 0.15 foot which is much less than the recorded rise.

Considering the fact that the cap-rock in the center of this dome is overlain by 700 to 1000 feet of soft unconsolidated sediments it is thought that ½ foot elevation at the surface would be likely to require several feet of elevation at the top of the cap. To the writer, this thought makes the rising salt theory seem the more likely.

GENERAL DISCUSSION—SUBSIDENCE

In an area where the force of gravity is so important, local irregularities in density may give rise to slump adjustment. A relatively heavy mass represented by a large sand bar or a reef may by its excess density cause earth movement. Small areas of uplift may be due to differential pull of gravity on formations of widely different densities. This is believed to be true in the case of rising salt plugs.

PSEUDO-DIASTROPHIC FEATURES

Many reports of diastrophic movement involve failures of some man-made structure. In such instances, the investigator should proceed with extreme caution lest he be misled by a failure which was the result of human weakness. If possible, decision should be deferred until a detailed investigation is conducted by a competent engineer. The following list includes a few items which give some idea of the things which might be considered.

[46] C. M. Sampson, personal communication.

[47] Archer H. Marx, "Hoskins Mound Salt Dome, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 2 (February, 1936), pp. 155–78.
———, *Gulf Coast Oil Fields* (1936), pp. 833–56.

In pipe failures

1. Original quality of pipe
2. Condition of pipe at time of failure
3. Was line properly located with respect to slopes and other structures?
4. Was pipe properly laid with respect to depth, joints, *et cetera?*
5. Were there irregularities in foundation?

In case of structural failures

1. Were specifications adequate?
2. Was construction properly supervised?
3. Was foundation properly prepared?
4. If a road, was there exceptional concentration of traffic?
5. Was proper maintenance supplied?

The foregoing list is not intended to be complete, but it illustrates the importance of an investigation of the engineering aspects.

INDIAN MIDDENS IN CORPUS CHRISTI AREA, NUECES COUNTY, TEXAS P-1

In 1928, R. A. Jones[48] reported the presence of mounds of shells on the bluffs near the bays of the Corpus Christi area, Nueces County, Texas, and concluded that they represented recently uplifted shore lines (recent diastrophic movement). After an exhaustive survey of these shell mounds and associated Indian burial grounds, G. C. Martin,[49] 1930, reported that they were associated with the camp sites of mollusk-eating Karankawa Indians. Martin reported that in the shell heaps he found fragments of Indian pottery, burned bones of game animals, buried shells, and other artifacts. There now seems to be little doubt that these shell mounds are of Indian origin and belong to the class of pseudo-diastrophic evidence.

PSEUDO-EARTHQUAKE EAST OF PADRE ISLAND, TEXAS P-2

J. G. Burr, aquatic biologist with the Game, Fish, and Oyster Commission of Texas, reported that something resembling an earthquake occurred on the shore of the Gulf of Mexico on July 3, 1935, approximately 60 miles east of Padre Island. Many tons of fish were killed and hydrogen sulphide gas was produced. The United States Coast and Geodetic Survey was called on to investigate the possibility of an earthquake but found no actual evidence of any such occurrence.

W. Armstrong Price[50] reports on this matter that the fish were probably killed by a severe flood of fresh water from the Nueces River. Also killed were many types of marine organisms among which were some jelly fish and associated echinoderms. These organisms produced sulphurous acid and a greenish gas when stirred up by the Gulf spray. Clyde T. Reed, biologist, is said to have produced the same gas in a laboratory flask by shaking the dead animals in sea water. This report was therefore classified as pseudo-diastrophic.

[48] R. A. Jones, "Evidence of Recent Uplift on the Gulf," *Oil and Gas Jour.*, Vol. 26, No. 46 (April 5, 1928).

[49] G. C. Martin, "Two Sites on the Callo Del Oso, Nueces County, Texas," *Bull. Texas Archaeol. and Paleontol. Soc.*, Vol. 2, pp. 7–17.

[50] W. Armstrong Price, personal communication.

WATER-MAIN BREAKS AT CUERO, TEXAS P-3

J. M. Johnson,[51] City engineer of Cuero, Texas, DeWitt County, reports that the City of Cuero experienced more broken water mains in the year 1945 than in the 10 years previous. Johnson reports that four breaks in the city water main occurred almost simultaneously along the main business street. The mains appeared to be in good condition and broke straight across as though cut. Some of the breaks occurred at points in a straight line, suggesting fault origin. The ground was dry at the time the four breaks occurred simultaneously. Johnson attributed the breaks to stresses set up by earth movements. No earthquake occurred in Cuero at this time. So far as the writer has been able to determine, no detailed engineering report was made on the subject and no geologic investigation was carried out on the ground.

John Cunningham,[52] superintendent of waterworks for the City of Corpus Christi, reports that in the fall of 1945 he noted many breaks in small cast-iron water mains in that city. He attributes the breaks to contraction of the mains due to entrance of cold water at times when the ground is either too dry or still warm so that it is not in condition to contract with the mains. In this connection, W. Armstrong Price[53] reports that the prairie in South Texas was much drier in the fall of 1945 than at any time since 1941. The numerous breaks of the 1945 season may therefore be attributed to normal dry-weather soil cracks. Price discussed the water-main problem in an interview for the Corpus Christi *Caller*, published on January 31, 1946. In his discussion, Price suggested that the water mains may have been broken by the formation of normal dry-weather cracks which are so common in South Texas. There seems to be insufficient evidence to attribute these water-main breaks to earth movements.

EXCESSIVE HIGHWAY REPAIRS, LIBERTY COUNTY, TEXAS P-4

Wallace Thompson[54] called the writer's attention to the fact that U. S. Highway 90 in western Liberty County, Texas, was undergoing repairs in the vicinity of the Esperson salt-dome oil field. It had been suggested that the paving failure may have been due to domal uplift. The writer discussed this problem with A. B. Middleton, State Highway engineer in the Liberty office. Middleton volunteered the information that the foundation under the failing pavement was faulty. The grade had been built up of gumbo soil by the drag-line "cast in" method. Test excavations revealed the presence, in the fill, of large tough balls of clay which were surrounded by soft mushy material and in some cases even void spaces. Middleton pointed out that in other parts of the county paving made under the same specifications but with uniform sandy loam subgrade was standing up satis-

[51] J. M. Johnson, personal communication.

[52] John Cunningham, personal communication.

[53] W. Armstrong Price, personal communication.

[54] Wallace Thompson, personal communication.

factorily. This discussion seemed definitely to eliminate the theory of failure due to uplift.

CONCLUSIONS

Earthquakes will probably continue in the Gulf Coast. Faulting is taking place in the Gulf Coastal Plain at the present time. Warping, local subsidence, and uplift are also active. In other words, the basin of the Gulf of Mexico is an area of active diastrophism.

In this activity, the force of gravity plays a very important role. Compaction can be an important cause or result, in movements of Coastal Plain sediments. Microseisms may aid in some movements. Local subsidence is likely to occur wherever support is unequal or whenever there are large local variations in density. Small areas of uplift may be due to differential gravity. Many of the regional faults in the Gulf Coastal Plain may be the result of extension of the section due to gravitational migration of soft sediments toward the basin of the Gulf of Mexico. These faults show a striking similarity to slump faults noted around areas of local subsidence. The migration may have been activated by microseisms and earthquake shocks. Aerial photographs are useful in the search for recent and historic diastrophism which often affects physiography.

More publicity on the subject of historic diastrophism should bring forth much more evidence.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 227-273, 3 FIGS.

MARINE JURASSIC OF BLACK HILLS AREA, SOUTH DAKOTA AND WYOMING[1]

RALPH W. IMLAY[2]
Washington, D. C.

ABSTRACT

In the Black Hills area the marine Jurassic rocks comprising the Gypsum Spring and Sundance formations represent the upper Bajocian, Bathonian, Callovian, and Oxfordian stages of the Middle and Upper Jurassic. A minor disconformity was developed during the upper Bathonian and a major, regional disconformity during the middle to upper Callovian. Subdivisions of the Sundance formation from base to top are herein defined as the Canyon Springs sandstone member, the Stockade Beaver shale member, the Hulett sandstone member, the Lak member, and the Redwater shale member. Sandy sediments in the lower four members were probably derived locally from the east or southeast, in the upper member mainly from the west. The Gypsum Spring formation represents the first widespread invasion and withdrawal of marine waters during the Jurassic in the Western Interior region. It is Middle Jurassic in age and correlative with the Gypsum Spring and Sawtooth formations farther west. The Canyon Springs sandstone member and the Stockade Beaver shale member represent a widespread marine invasion at the beginning of the Upper Jurassic and are correlative with the lower part of the Sundance formation of north-central Wyoming, the "Lower Sundance" of central Wyoming, and the Rierdon formation of Montana. The overlying marine Hulett sandstone member is correlative with similar sandstone in the "Lower Sundance" formation in central Wyoming. It is probably present in North Dakota and southeastern Montana. It is missing in the outcrop in Montana but may be represented there by shale or shaly limestone at the top of the Rierdon formation. It probably passes westward in Wyoming into the upper part of the Twin Creek limestone. The Lak member consists of redbeds, is apparently non-marine, and is correlative at least in part with the Entrada and Preuss sandstones farther west. It is possibly present in North Dakota but has not been identified in Montana. The Redwater shale member represents the last Jurassic marine invasion in the Western Interior region of the United States. It is mainly or entirely Oxfordian in age and correlative with highly glauconitic sandstone and shale farther west, variously called Swift formation, Stump sandstone, Curtis formation, and "Upper Sundance" formation.

INTRODUCTION

The marine Jurassic rocks of the Black Hills in western South Dakota and eastern Wyoming were examined by the writer, assisted by Wm. G. Saalfrank, during the summer of 1945, in order to ascertain the lithologic and faunal units included in the Sundance formation and its stratigraphic relationships to marine Jurassic rocks elsewhere in the Western Interior region. In the summer of 1946 the area was revisited briefly by John B. Reeside, Jr., J. D. Love, and the writer primarily to compare the Jurassic sequence with that in the Hartville uplift of eastern Wyoming. Fortunately, many ammonites and other mollusks were found at several levels within the Sundance formation, permitting very close age determinations and regional correlations whose implications will change some current ideas of Jurassic history. These discoveries were, of course, greatly facilitated by the previous investigations of N. H. Darton, whose excellent discussions of the Sundance formation and its subdivisions in the Black Hills were found to be essentially correct. Many of the conclusions drawn herein are based on field and laboratory studies by the writer during the past two years and will be substan-

[1] Manuscript received, August 5, 1946. Published by permission of the director of the Geological Survey.

[2] Geologist, Geological Survey, United States Department of the Interior.

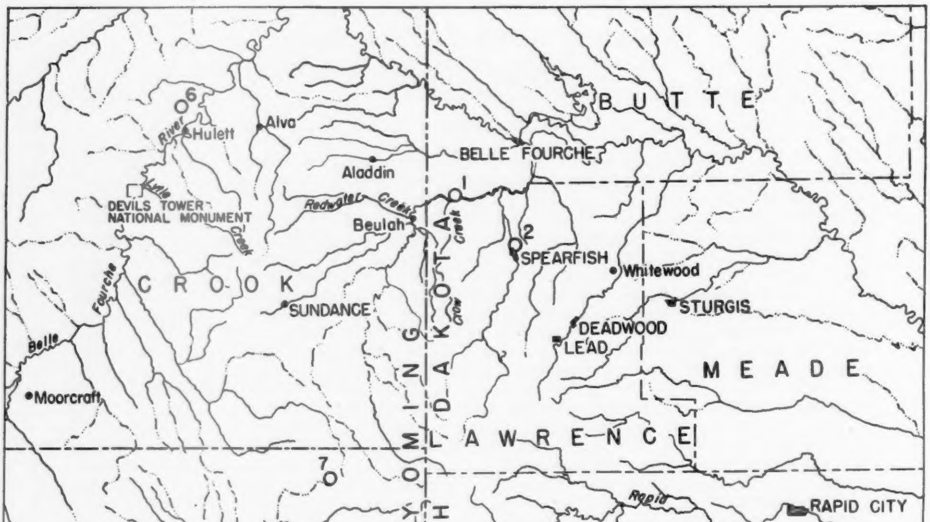


FIG. 1.—Index map of Black Hills area.

tiated by later publications. In the Black Hills the continental Jurassic was only examined incidentally and all the stratigraphic studies should be regarded as preliminary. Undoubtedly many more interesting facts will be found when the Jurassic rocks are studied in detail.

The writer is greatly indebted to John B. Reeside, Jr., and J. D. Love for their highly pertinent observations and suggestions in the field and their critical reading of the manuscript. To J. D. Love in particular belongs credit for recognizing a sandstone unit as probably representing the Nugget sandstone, for confirming the presence of the Gypsum Spring formation, and for showing the relationship of these formations to the basal sandstone of the Sundance formation.

STRATIGRAPHIC SUMMARY

The Jurassic rocks in the Black Hills area (Fig. 1) are included in the Nugget (?) sandstone, the Gypsum Spring formation, the Sundance formation, the Unkpapa sandstone, and the Morrison formation. The latter two were only examined incidentally and will barely be mentioned herein. The 60 feet or less of Nugget (?) sandstone was not examined critically and is discussed mainly to show its stratigraphic relationship. The marine Jurassic includes the Gypsum Spring and Sundance formations and represents much of the Middle and Upper Jurassic. The Gypsum Spring formation ranges from a feather-edge to 45 feet in thickness, represents the upper Bajocian and Bathonian stages, and is separated from adjoining formations by disconformities. The Sundance formation ranges from 200 to nearly 350 feet in thickness and represents the Callovian and Oxfordian stages. It consists of five members of which the upper member is marked basally by a disconformity (Table I). Sandy sediments in the basal member were probably derived locally, in the next two overlying members were derived from the east or southeast, in the next member were probably derived from the east or south, and in the upper member were derived mainly from the west, or from reworking of the underlying beds. Thicknesses of the formations and members at various localities are shown in Table II.

The Nugget (?) sandstone crops out only in the southwestern part of the Black Hills, ranges from a feather-edge to 60 feet in thickness, and consists mostly of massive, cross-bedded, cliff-forming sandstone. It is mostly fine-grained but contains some streaks of rather large polished grains and locally has pitted and polished pebbles of a dark gray chert-like rock. Its contacts are sharp and apparently disconformable. It is probably a continental deposit of desert origin. Its assignment to the Jurassic is uncertain owing to lack of fossils.

The Gypsum Spring formation, ranges from 1 to 45 feet in thickness, and is present only in the northern part of the Black Hills. In the west-central and northeastern parts of the Black Hills it is represented by 8 to 45 feet of white gypsum interbedded with some soft maroon siltstone and shale. The gypsum locally grades laterally into dolomite and limestone. In the northwestern part of the Black Hills the formation is represented by 1 to 21 feet of interbedded,

TABLE I

CORRELATION OF JURASSIC FORMATIONS IN

JURASSIC	EUROPEAN STAGES (ARKELL, 1946)	ENGLISH FORMATIONS (AFTER ARKELL, 1933)	NORTHWEST EUROPE STANDARD ZONES (ARKELL, 1946)	CHARACTERISTIC FOSSILS IN THE WESTERN INTERIOR REGION	WEST-CENTRAL AND NORTH-CENTRAL MONTANA		
UPPER	PORTLANDIAN	PURBECK BEDS					
		PORTLAND BEDS	TITANITES GIGANTEUS				
			KERBERITES OKUSENSIS			?	
			GLAUCOLITHITES GOREI	VETULONAIA SPP. AND GYRAULUS VETERNUS		MORRISON FORMATION	
			ZARAISKITES ALBANI				
	KIMMERIDGIAN	KIMMERIDGE CLAY	PAVLOVIA PALLASIOIDES				
			PAVLOVIA ROTUNDA				
			PECTINATITES PECTINATUS				
			SUBPLANITES WHEATLEYENSIS				
			SUBPLANITES SP				
			GRAVESIA GIGAS				
			GRAVESIA GRAVESIANA				
			AULACOSTEPHANUS PSEUDOMUTABILIS				
			RASENIA MUTABILIS				
			RASENIA CYMODOCE				
			PICTONIA BAYLEI				
	OXFORDIAN	CORALLIAN BEDS	RINGSTEADIA PSEUDOCORDATA		ELLIS GROUP	SWIFT FORMATION	
			DECIPIA DECIPIENS				
			PERISPHINCTES CAUTISNIGRAE				
			PERISPHINCTES PLICATILIS				
		OXFORD CLAY	CARDIOCERAS CORDATUM	CARDIOCERAS SPP.			
			QUENSTEDTOCERAS MARIAE	CARDIOCERAS CORDIFORME			
	CALLOVIAN		QUENSTEDTOCERAS LAMBERTI	QUENSTEDTOCERAS COLLIERI			
			PELTOCERAS ATHLETA				
			ERYMNOCERAS CORONATUM				
			KOSMOCERAS JASON				
		KELLAWAYS BEDS	SIGALOCERAS CALLOVIENSE	KEPPLERITES GOWERICERAS		RIERDON FORMATION	
			PROPLANULITES KOENIGI				
		CORNBRASH BEDS	MACROCEPHALITES MACROCEPHALUS	ARCTICOCERAS			
MIDDLE	BATHONIAN		CLYDONICERAS DISCUS	ARCTOCEPHALITES		SAWTOOTH FORMATION	MARINE SILTSTONE
		GREAT OOLITE	(NOT YET DETERMINED)				DARK GRAY SH. AND LS. WITH BASAL SS. GRADE EASTWARD INTO GYPSUM AND RED BEDS.
	BAJOCIAN	INFERIOR OOLITE	PARKINSONIA PARKINSONI	STEMMATOCERAS AND DEFONTICERAS (NOT ZONED)			
			STEPHANOCERAS HUMPHRIESIANUM				
			OTOITES SAUZEI				
			SONNINIA SOWERBYI				
			LUDWIGIA MURCHISONAE				
			LIOCERAS OPALINUM				
LOWER	TOARCIAN	UPPER LIAS	LYTOCERAS JURENSE	?			
			HILDOCERAS BIFRONS				
			HARPOCERAS SERPENTINUM				
			DACTYLIOCERAS TENUICOSTATUM				
	PLIENSBACHIAN	MIDDLE LIAS	PALTOPLEUROCERAS SPINATUM				
			AMALTHEUS MARGARITATUS				
		LOWER LIAS	PRODACTYLIOCERAS DAVOEI				
			TRAGOPHYLLOCERAS IBEX				
			UPTONIA JAMESONI				
	SINEMURIAN		ECHIOCERAS RARICOSTATUM				
			OXYNOTICERAS OXYNOTUM				
			ASTEROCERAS OBTUSUM				
			ARIETITES TURNERI				
			ARNIOCERAS SEMICOSTATUM				
			CORONICERAS BUCKLANDI				
	HETTANGIAN		SCAMNOCERAS ANGULATUM				
			PSILOCERAS PLANORBIS				

I

PARTS OF WESTERN INTERIOR REGION

SOUTH-CENTRAL AND SOUTHERNMOST MONTANA	NORTHERN PART OF BIG HORN BASIN NORTH-CENTRAL WYOMING	WIND RIVER BASIN OF CENTRAL WYOMING	FREEDOM QUADRANGLE OF SOUTHEASTERN IDAHO	SAN RAFAEL SWELL OF MIDDLE EASTERN UTAH	BLACK HILLS, WESTERN SOUTH DAKOTA AND NORTHEASTERN WYOMING
?	?	?	?	?	?
MORRISON FORMATION	MORRISON FORMATION	MORRISON FORMATION	EPHRAIM CONGLOMERATE	MORRISON FORMATION	MORRISON FORMATION
ELLIS GROUP: SWIFT FORMATION	SUNDANCE FORMATION: GLAUCONITIC SS. AND SHALE LOCALLY CONGLOMERATIC AT BASE	"UPPER SUNDANCE": GLAUCONITIC SANDSTONE AND SHALE	? STUMP SANDSTONE	SAN RAFAEL GROUP: SUMMERVILLE FORMATION; CURTIS FORMATION	SUNDANCE FORMATION: REDWATER SHALE MEMBER
	?	?	PREUSS SANDSTONE	ENTRADA SANDSTONE ?	LAK MEMBER
RIERDON FORMATION	CALCAREOUS GRAY SHALE, SOME LIMESTONE	"LOWER SUNDANCE": RED BEDS AT TOP, MOSTLY GRAY SS.; GRAY SHALE AND THIN LIMESTONE, SANDIER EASTWARD	? TWIN CREEK LIMESTONE	CARMEL FORMATION	HULETT SANDSTONE MEMBER; STOCKADE BEAVER SHALE MEMBER; CANYON SPRINGS SS MEMBER
GYPSUM SPRING FORMATION: RED SH. AND SILTSTONE; MARINE SHALE AND LIMESTONE; MASSIVE GYPSUM AND RED BEDS	GYPSUM SPRING FORMATION: RED SHALE AND SILTSTONE; GRAY SH. AND LS. grading eastward INTO DOLOMITE AND RED SHALE; MASSIVE GYPSUM AND RED BEDS	GYPSUM SPRING FORMATION: DOLOMITE, LIMESTONE, AND SHALE; MASSIVE GYPSUM AND RED BEDS		?	? GYPSUM SPRING FORMATION
		? NUGGET SANDSTONE ?	? NUGGET SANDSTONE ?	JURASSIC (?) GLEN CANYON GROUP: ? NAVAJO SANDSTONE; ? KAYENTA FORMATION; WINGATE SS.	?

JGK

fossiliferous gray shale, limestone, and dolomite. The formation rests sharply and unconformably on the slightly irregular surface of the Spearfish formation of Triassic (?) age. This is clearly evident in the field except for the gypsiferous facies, which has formerly been included in the Spearfish formation on the basis

TABLE II
THICKNESSES IN FEET OF SOME JURASSIC UNITS IN BLACK HILLS AREA

Localities	Nugget(?) Sandstone	Gypsum Spring Formation	Sundance Formation					
			Canyon Springs Sandstone Member	Stockade Beaver Shale Member	Hulett Sandstone Member	Lak Member	Redwater Shale Member	Total Thickness (Feet)
SE. of Hot Springs near Fall River, E. ½ of Sec. 24, T. 7 S., R. 5 E., S. D.			25	9	38	80	90	242
East of Hot Springs, E. ½ Sec. 13, T. 7 S., R. 5 E., S. D.			2	35	23	80	80	220
Two miles NW. of Buffalo Gap, Sec. 13, T. 6 S., R. 6 E., S. D.			40	6	37	65	100±	248
Six miles S. of Rapid City, SE. ¼ of Sec. 34, T. 1 N., R. 7 E., S. D.			1½	63	23	76	69+*	232+ Incomplete
One mile N.-NE. of center of Spearfish, Sec. 3, T. 6 N., R. 2 E., S. D.		25–40		60	97	60	105+	322+
Redwater Creek NE. of Crow Creek, S. ½ of Sec. 2, T. 7 N., R. 1 E., S. D.		29		52	121	50	136	359
Bush Canyon 2½ miles N. of Hulett, Secs. 25 and 36, T. 55 N., R. 65 W., Wyo.		21		76	82	42	163	363
Nine miles S.-SW. of Sundance, Sec. 31, T. 50 N., R. 63 W., Wyo.			6	50				
Stockade Beaver Creek, 5 miles NE. of Newcastle, Sec. 18, T. 45 N., R. 60 W., Wyo.		8–12		63	69	80	107 Incomplete	319+ Incomplete
Elk Mountain 15 miles SE. of Newcastle, S. ½ of Sec. 19, T. 4 S., R. 1 E., S. D.	4–10	5–10	1	64	55	58	188	366
Near Pass Creek 3 miles NE. of Dewey, NE. ¼ of Sec. 10, T. 6 S., R. 1 E., S. D.			10–25	40	55	75	125	305+
Three miles W.-NW. of Minnekahta, S. ½ of Sec. 11, T. 7 S., R. 3 E., S. D.	29		13	48	32	60	107 Incomplete	260 Incomplete
Two miles E.-SE. of Minnekahta, S. ½ of Sec. 21, T. 7 S., R. 4 E., S. D.				64 Incomplete	47	100	104	315 Incomplete

* The Rapid City Airport Well No. 2 in Sec. 13, T. 2 N., R. 8 E., is logged as having 205 feet of Redwater shale.[3]

[3] J. P. Gries, "Two Deep Water Wells near Rapid City, South Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943). p. 649.

of lithologic resemblances. The Gypsum Spring formation is related faunally to the overlying Jurassic beds and represents part of the Middle Jurassic. Its thickness and facies relationships suggest that it filled in the irregularities of an old erosion surface. A widespread, gentle uplift occurred at the end of Gypsum Spring time.

The Canyon Springs sandstone member of the Sundance formation is 45 feet or less in thickness and is well developed only along the southern and western

margins of the Black Hills. It consists generally of gray to white, massive, fine-grained sandstone but in places changes laterally or vertically into yellowish or salmon-colored sandstone and may include beds of maroon to gray shale. It overlaps onto the Gypsum Spring formation, the Nugget (?) sandstone, and the Spearfish formation and locally fills channels in them. It contains fossils of the same age as in the base of the overlying Stockade Beaver shale member.

The Stockade Beaver shale member of the Sundance formation ranges in thickness from 5 to 85 feet and averages about 50 feet. It consists mainly of gray, soft, fissile, calcareous shale, but toward the northern side of the Black Hills contains some silty to sandy material and becomes slightly gypsiferous. A disconformity at its base may be indicated by pebbles of hard, metamorphic rocks and of quartz just above a sharp contact with the Gypsum Spring formation. The Stockade Beaver shale member is correlated basally with the basal part of the Sundance formation of north-central Wyoming, the "Lower Sundance" formation of central Wyoming and the Rierdon formation of Montana on the presence of *Arcticoceras henryi* (Meek and Hayden) and related species. The occurrence of a few specimens of *Gryphaea nebrascensis* (Meek and Hayden) in the middle part of the Stockade Beaver strata suggests a correlation with the *Gowericeras* beds of Montana and Wyoming, as *G. nebrascensis* first appears in abundance in those beds. Evidently the main source of sediment was toward the east or southeast, as the Stockade Beaver shale member is less calcareous and more silty and sandy than equivalent beds in Montana and north-central Wyoming.

The Hulett sandstone member of the Sundance formation consists mainly of grayish, fairly hard, thin- to thick-bedded, calcareous, micro-glauconitic, ripple-marked sandstone. Along the southeastern and southern margins of the Black Hills it ranges from 25 to 55 feet in thickness and is characterized by thin-bedded sandstone interbedded with considerable gray sandy shale. Northward, it thickens to about 120 feet in the northern part of the Black Hills, and the sandstone layers become harder, more massive, and white, buff, or reddish. It grades within a few feet into the adjoining members. The Hulett sandstone member contains some marine fossils that do not furnish an exact correlation. However, its lithologic character and stratigraphic position are similar to that of the gray sandstone near or locally at the top of the "Lower Sundance" of the Wind River basin of central Wyoming. An easterly source for the sandy sediment seems probable.

The Lak member of the Sundance formation ranges in thickness from about 25 to 100 feet. It consists mainly of unfossiliferous, maroon, fine-grained sandstone and siltstone, but most sections have several thin beds of greenish siltstone and one or two beds of white, pink, or red medium-grained sandstone. The coarser sandstones are most common in the southeastern part of the Black Hills. The member is differentiated from the Spearfish formation by lacking gypsum in most places and being slightly lighter in color. Its upper contact is sharp and disconformable. Stratigraphic position and lithologic similarity suggest correlation with the Entrada sandstone of Utah, the Preuss sandstone of Idaho and westernmost

Wyoming, and the redbeds at the top of the "Lower Sundance" of central Wyoming. These red-colored formations and members appear to be mostly continental, partly water-laid and partly wind-laid, and were probably formed when the southern end of the Jurassic seaway was suddenly cut off by extensive uplift in Montana, particularly along an easterly trend, at the end of Rierdon time, or during the middle Callovian.

The Redwater shale member of the Sundance formation ranges in thickness from 80 to 190 feet, or more. It consists mainly of greenish gray, soft, fissile shale, but includes some soft glauconitic sandstone in the lower 20 to 30 feet, and thin beds of oölitic to coquinoid limestone in the upper half. Belemnites are generally abundant. The contact with the overlying Morrison formation or Unkpapa sandstone is transitional. Correlation faunally is made with the Curtis formation of Utah, the Stump sandstone of eastern Idaho and westernmost Wyoming, the Swift formation of Montana, the highly glauconitic sandstone and shale forming the upper part of the Sundance formation of north-central Wyoming, and the "Upper Sundance" of central Wyoming. Superposition of the normal marine beds of the Redwater shale member on the non-fossiliferous redbeds of the Lak member suggests a rapid marine flooding. Sources of clastic sediments were mostly toward the west.

NUGGET (?) SANDSTONE

Distribution and general discussion.—Massive sandstones tentatively assigned to the Nugget sandstone occur in two small areas in the southwestern part of the Black Hills. One area of outcrops extends from 2 to 7 miles west-northwest of Minnekahta. The other extends for several miles along the east side of Elk Mountain, roughly from 13 to 16 miles southeast of Newcastle. Darton[4] considered the outcrops on Elk Mountain as part of the Spearfish formation as they underlie massive gypsum. He considered the sandstone outcrops west of Minnekahta as the basal part of the Sundance formation because of the presence of fossils,[5] although the fossils actually occur only in the upper white sandstones herein named Canyon Springs sandstone member of the Sundance formation. Bartram[6] considered the massive sandstones west of Minnekahta as the basal sandstone of the Sundance formation and equivalent to the Nugget sandstone of western Wyoming. The writer during the course of field work was so impressed with the common occurrence of marine fossils in the sandstones at the base of the Jurassic sequence that he doubted if any of the beds were equivalent to the Nugget sandstone. Later during a field trip with John B. Reeside, Jr., and J. D. Love, it was agreed that the marine sandstones at the base of the Sundance formation should

[4] *Op. cit.* (1904), p. 3.

[5] Darton and Smith, *op. cit.* (1904), p. 4.

[6] John G. Bartram, "Triassic-Jurassic Red Beds of the Rocky Mountain Region," *Jour. Geology*, Vol. 38 (1930), p. 339.

———, "The Stratigraphy and Structure of Eastern Wyoming and the Black Hills Area," *Fourteenth Annual Field Conference of the Kansas Geol. Soc.* (1904), p. 117.

be considered a member of that formation, but that the massive, cross-bedded, salmon-colored sandstone underlying the marine sandstones locally west of Minnekahta were probably correlative with the Nugget sandstone.

Stratigraphic and lithologic features.—The Nugget (?) sandstone exposed west of Minnekahta ranges from a feather-edge to at least 60 feet in thickness and consists mainly of massive, cliff-forming, salmon-colored sandstones. Locally some beds near the base are yellowish and may be laminated. The upper few feet are white in some sections, apparently owing to bleaching. Large-scale cross-bedding is common. The grain size is rather fine but there are many streaks consisting of large grains that may be highly polished. Pitted and polished dark gray chert-like pebbles as much as two inches in diameter occur locally in the lower part of the sandstone. The contact with the Spearfish formation is sharp but fairly even. The contact with the overlying white marine sandstone at the base of the Sundance formation is sharp and in places very irregular. A section of the Nugget (?) sandstone exposed on a spur about 3 miles west-northwest of Minnekahta is here described.

NUGGET (?) SANDSTONE ABOUT 3 MILES WEST-NORTHWEST OF MINNEKAHTA IN S. ½ OF SEC. 11, T. 7 S., R. 3 E., FALL RIVER COUNTY, SOUTH DAKOTA

	Feet
4. Sandstone, salmon-colored, massive, cliff-forming, fairly soft, coarsely cross-bedded, moderate- to fine-grained, some grains highly polished; some fine chert grit throughout, weathers brick red; base somewhat irregular and bears some pitted and polished dark gray chert-like pebbles, thickens westward and thins southward	21
3. Sandstone, yellow	3
2. Sandstone, yellow to salmon-colored, laminated, appears to thicken considerably toward the southwest	2
1. Sandstone, salmon-colored, massive, contains a few chert-like pebbles as much as 2 inches in diameter, rests fairly evenly on the Spearfish formation	3
Total thickness	29

On another northward-trending spur about ¼ mile farther west, the Nugget (?) sandstone consists almost entirely of massive salmon-colored sandstone, is somewhat thicker, and lacks pebbles. About 7 miles west-northwest of Minnekahta in Sec. 6, T. 7 S., R. 3 E., a high bluff just north of the road exposes about 50 feet of massive, cross-bedded, salmon-colored sandstone overlain by about 10 feet of white sandstone that appears to be bleached because the cross-bedding cuts through the color change. These beds are overlain along a slightly irregular surface by about 3 feet of marine sandstone belonging to the Canyon Springs sandstone member of the Sundance formation.

The so-called Nugget (?) sandstone along the east side of Elk Mountain from 13 to 16 miles southeast of Newcastle is massive, moderately hard, medium- to fine-grained, salmon-colored, weathers brick red, and ranges in thickness from 4 to 10 feet. It is lighter in color and harder than the the underlying Spearfish formation. Its upper and lower contacts are sharp. It is tentatively referred to the Nugget (?) sandstone because it directly underlies a thick bed of massive gypsum representing the Gypsum Spring formation. However, it consists of less

pure sandstone than the Nugget (?) sandstone west of Minnekahta and may actually be part of the Gypsum Spring formation. The best and most accessible exposures may be found in Sec. 8, T. 4 S., R. 1 E., east-southeast of the Lookout Tower on Elk Mountain.

Correlation.—Definite identification of the Nugget sandstone in the Black Hills must await subsurface studies, but its occurrence there seems possible inasmuch as it has been traced with reasonable certainty as far east at the Hartville uplift.

Origin.—The Nugget (?) sandstone in the Black Hills may be continental as suggested by coarse cross-bedding, its massive appearance, the absence of marine fossils, the polished appearance of some of the larger sand grains, and the presence of pitted and polished chert-like pebbles.

GYPSUM SPRING FORMATION

Definition.—The Gypsum Spring formation in the Wind River Basin of central Wyoming has been defined by Love[7] as including 250 feet or less of gypsiferous beds disconformably underlying beds that have generally been referred to the Sundance formation. The lower part of the Gypsum Spring formation of central Wyoming is characterized by 50 to 125 feet of massive white gypsum underlain by a bed of red sandy shale. Its upper part consists of alternating beds of gypsum, red shale, dolomite, and limestone. Many marine fossils from limestone and dolomite beds in the upper part have been identified by the writer as Middle Jurassic because they bear considerable resemblance to fossils in the Sawtooth formation of the Sweetgrass arch area of northwestern Montana and in the Great Oölite of England. From the lower part of the marine shales and limestones immediately overlying the Gypsum Spring formation have been obtained Upper Jurassic ammonites and pelecypods characteristic of the lower part of the Rierdon formation of Montana.

In Montana and the bordering areas of Wyoming a sequence of gypsiferous beds, occupying the same stratigraphic position as the Gypsum Spring formation farther south, has been identified on the surface[8] as far west as Indian Creek in the Madison Range and Belt Creek in the Little Belt Range,[9] as far east as the northeast end of the Bighorn Mountains, and as far north as the Judith and Moccasin mountains. In the subsurface a similar gypsiferous sequence occurs in

[7] J. D. Love, "Geology along the Southern Margin of the Absaroka Range, Wyoming," *Geol. Soc. America Spec. Paper 20* (1939), p. 45.
——— (and others), "Stratigraphic Sections and Thickness Maps of Jurassic Rocks in Central Wyoming," *U. S. Geol. Survey Prelim. Chart 14*, Oil and Gas Investig. Ser. (1945).

[8] L. S. Gardner, T. A. Hendricks, H. D. Hadley, and C. P. Rogers, Jr., "Mesozoic and Paleozoic Formations in South-Central Montana," *U. S. Geol. Survey Prelim. Chart 18*, Oil and Gas Investig. Ser. (1945).
H. D. Hadley, L. S. Gardner, and C. P. Rogers, Jr., "Subsurface Stratigraphy of Lower Mesozoic and Upper Paleozoic Formations in the Basin Area of South-Central Montana," *ibid. Chart 19* (1945).

[9] W. A. Cobban, "Marine Jurassic Formations of Sweetgrass Arch, Montana." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 1275, 1298.

north-central Montana a little east of the Sweetgrass Hills[10] and extends into eastern Montana at least as far as the Porcupine dome in north-central Rosebud County north of Forsyth.[11] These beds differ from the Gypsum Spring formation of central Wyoming mainly by having in addition an upper gypsiferous redbed member and by changing progressively westward and northwestward into the normal marine Sawtooth formation of western Montana. They are overlain in Montana and in the Big Horn Basin of Wyoming by dark marine shales which basally contain species of *Arcticoceras*, including *A. henryi* (Meek and Hayden), and a little higher contain species of *Gowericeras* and *Cadoceras*. It seems logical to extend the term Gypsum Spring formation to include these gypsiferous beds in northern Wyoming and in Montana.

In the Black Hills area the rather thin beds directly below the Sundance formation are herein called the Gypsum Spring formation, because they occupy the same stratigraphic position as the Gypsum Spring formation in north-central Wyoming and southernmost Montana, directly beneath beds containing *Arcticoceras henryi* (Meek and Hayden), and because they show considerable lithologic resemblance to the typical Gypsum Spring formation. If the correlation is correct the formation extends across the Powder River Basin in the subsurface, a distance slightly more than 100 miles.

Stratigraphic and lithologic features.—The lowest marine Jurassic beds, herein included in the Gypsum Spring formation (Figs. 2 and 3) comprise two laterally intergrading facies. One facies consists of gypsum, generally interbedded with soft maroon siltstone and shale, and attains locally 45 feet in thickness. It extends roughly on the western side of the Black Hills from Elk Mountain to Sundance and on the northeast side from about 10 miles south of Sturgis to the vicinity of Spearfish. A second facies consists of interbedded gray shale, limestone, and dolomite, occurs in the northwestern end of the Black Hills, attains at least 21 feet in thickness, and is particularly well exposed on the road from Hulett to Alva.

The gypsiferous facies along the western side of the Black Hills consists mainly of a massive bed of white gypsum, from 8 to 30 feet thick, above the redbeds of the Spearfish formation and beneath gray marine shale, but near Sundance the gypsum is overlain by a few feet of red shale and siltstone. About 9 miles south-southwest of Sundance in Sec. 32, T. 50 N., R. 63 W., Wyoming, the gypsum bed is locally absent. Along the northeastern side of the Black Hills the facies is marked by a bed of massive white gypsum, from 10 to 30 feet thick, that rests sharply on the slightly irregular surface of the Spearfish formation. Above follows as much as 15 feet of interbedded maroon, green, and gray shale and white gypsum. The gypsiferous facies was included by Darton[12] in the top of the Spearfish

[10] W. A. Cobban, *op. cit.*, pp. 1275, 1276.

[11] H. D. Hadley *et al.*, *op. cit.* (1945).

[12] N. H. Darton, "Geology and Water Resources of the Northern Portion of the Black Hills and Adjoining Regions in South Dakota and Wyoming," *U. S. Geol. Survey Prof. Paper 65* (1909), pp. 27-29

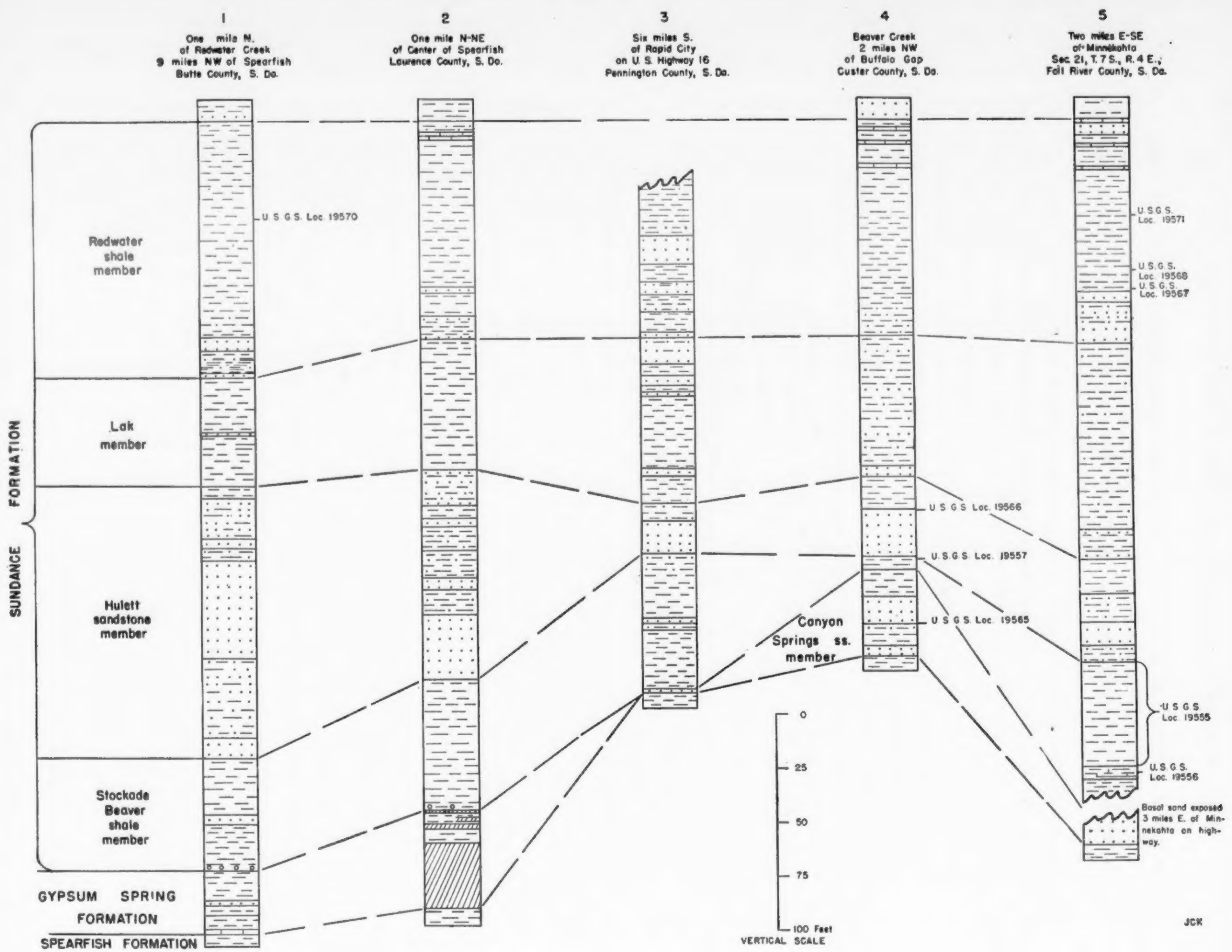


FIG. 2.—Columnar sections along eastern side of Black Hills.

FIG. 2.—Columnar sections along eastern side of Black Hills.

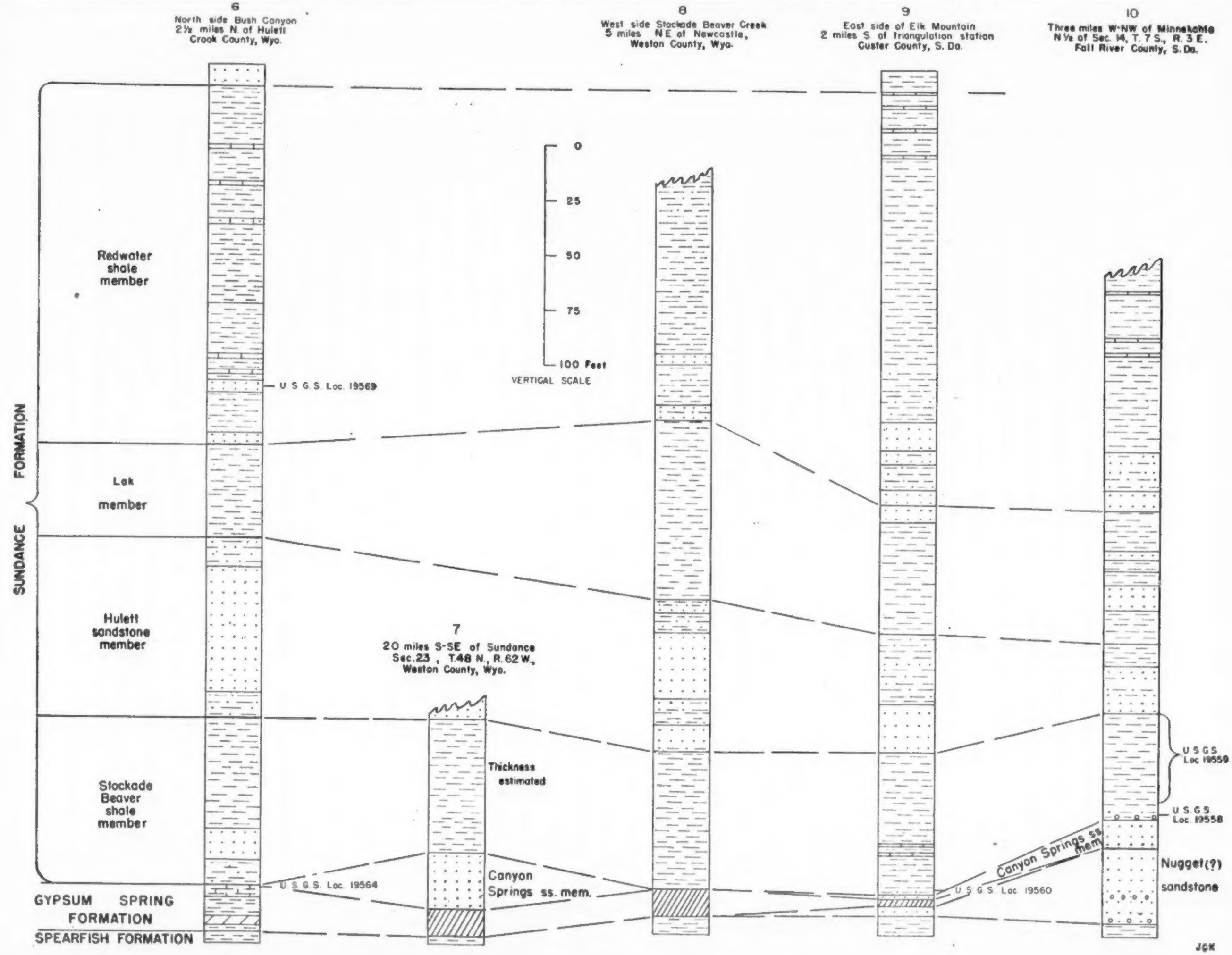


FIG. 3.—Columnar sections along western side of Black Hills.

formation, but it contains marine Jurassic fossils, interfingers laterally with dolomite and limestone that contains marine fossils, and makes a sharp, apparently unconformable contact with the redbeds of the underlying Spearfish formation. The mistake is readily understandable, as the similar-appearing Gypsum Spring formation of Wyoming was placed in the Chugwater formation until the discovery of fossils proved it to be of Middle Jurassic age. The redbeds in the Gypsum Spring strata of the Black Hills differ from the redbeds of the Spearfish formation by being softer, less silty and weathering to a pink that is distinctly different than the brick-red weathered surfaces of the Spearfish formation. The gypsum in the two units does not show any recognizable megascopic differences.

The second facies of the Gypsum Spring formation of the Black Hills area consists of fossiliferous gray, thin-bedded to shaly limestone interbedded with calcareous gray shale and dolomitic limestone or dolomite. On Lytle Creek, about 4 miles southeast of Devils Tower, the basal bed of the Jurassic consists of only one foot of shaly limestone containing many shells of *Ostrea* and *Gryphaea*. One mile southwest of Hulett in a highway cut the base of the Jurassic is represented by 14 feet of interbedded gray shale, dolomitic limestone, and dolomite containing chert. The highest beds bear *Gryphaea*, *Ostrea*, and *Camptonectes*. On the north side of Bush Canyon, 2½ miles north of Hulett, this basal facies is 21 feet thick and consists from top to bottom of 6 feet of highly fossiliferous shaly limestone, 8 feet of soft, gray shale, 4 feet of dolomite containing thin layers of chert, and 3 feet of gray shale resting sharply on the Spearfish formation. Farther north on the road from Hulett to Alva the basal shale is missing, and a dolomite containing small pockets of gypsum rests on the highly irregular surface of the Spearfish formation. This dolomite greatly resembles that at the base of the Jurassic near Redwater Creek, about 9 miles northwest of Spearfish. However, at the latter locality the Gypsum Spring formation is essentially the same as at Spearfish, except that a brecciated dolomite occupies the position of the massive gypsum bed at Spearfish. Reasons for considering these dolomitic beds part of the Gypsum Spring formation are that dolomitic beds have not been observed by the writer in any part of the overlying marine Jurassic in Montana and Wyoming; that they contain irregular, blocky masses of dark chert resembling that in the typical Gypsum Spring formation in central Wyoming; that some of the dolomites are brecciated, suggesting that they were once interbedded with gypsum; and that the dolomites grade laterally into limestone and gypsum. An excellent example of this gradation may be observed about 2 miles southeast of Whitewood on the east side of the road in Sec. 26, T. 6 N., R. 4 E. At this place the massive gypsum is replaced by 8 feet of limestone but ¼ mile farther south is replaced again by interbedded gypsum and limestone.

The Gypsum Spring formation of the Black Hills area rests sharply on the redbeds of the Spearfish formation. An unconformable contact is indicated by the slightly irregular surface of the Spearfish formation, by a knife-edge change in lithologic character at most localities and by the inclusion of fragments of red siltstone in the basal bed of the Gypsum Spring formation.

The contact of the Gypsum Spring formation with the overlying Canyon Springs sandstone member, or the Stockade Beaver shale member of the Sundance formation is marked by an abrupt change in lithologic character and is disconformable. On Elk Mountain 15 miles southeast of Newcastle and northward to Oil Creek, a distance of about 45 miles, the change is from massive white gypsum to gray shale; near Sundance and Spearfish and Sturgis the massive gypsum bed is separated from the stockade Beaver shale member by a few feet of redbeds; near Hulett, gray fossiliferous limestone is overlain by gray shale. North of Redwater Creek, about 9 miles northwest of Spearfish in Sec. 2, T. 7 N., R. 1 E., a dolomite bed at the base of the Gypsum Spring formation is overlain by about 26 feet of redbeds beneath the Stockade Beaver shale member. Two miles farther east the redbeds disappear and the dolomite bed is overlain directly by the Stockade Beaver shale member. Pebbles of a hard, dense, gray metamorphic rock were found in the basal foot of the Stockade Beaver strata 3 miles west-northwest of Minnekahta, near Pass Creek 3 miles northeast of Dewey, near Spearfish and at other places. A conglomerate of red siltstone and quartz was found in the base of the Stockade Beaver shale 1 mile north of Redwater Creek about 9 miles northwest of Spearfish. A conglomeratic sandstone was found by Darton[13] at the base of the gray shales northwest of Beulah and southwest of Aladdin. Quartz fragments, poorly rounded and as much as 3 inches in diameter, occur at the base of the member 7 miles west-northwest of Minnekahta.

These criteria, an abrupt lithologic change and the presence of a basal conglomerate in the overlying beds, have been used by Love[14] and others working in central Wyoming as evidence of a disconformity between the Gypsum Spring formation of that area and the overlying "Lower Sundance." If the criteria hold, then the disconformity persists into the Black Hills area, as the base of the Stockade Beaver shale member corresponds exactly, on the basis of fossils, with the base of the "Lower Sundance" of central Wyoming. From the writer's studies of the Jurassic fossils of Montana and Wyoming the disconformity would not represent more than upper Bathonian time at the end of the Middle Jurassic.

Typical sections of the Gypsum Spring formation of the Black Hills area are given at the end of this paper.

Correlation.—The limestone-dolomite facies in the northwestern part of the Black Hills is fairly fossiliferous. At Bush Canyon, 2½ miles north of Hulett, the uppermost bed has furnished (U. S. G. S. loc. 19564) ***Lingula brevirostris*** Meek and Hayden, ***Eumicrotis curta*** (Hall), ***E. orbiculata*** (Whitfield), ***Quenstedtia sublevis*** (Meek and Hayden) ***Volsella jurassica*** (Whitfield and Hovey). The basal limestone bed 4 miles southeast of Devils Tower on Lytle Creek has furnished (U. S. G. S. loc. 19562) ***Ostrea strigilecula*** White and ***Eumicrotis*** cf. ***E. orbiculata*** (Whitfield). As these fossils occur also in the Stockade Beaver shale member, the Gypsum Spring formation belongs with the overlying Jurassic sequence. For-

[13] *Op. cit.* (1909), p. 32.
[14] *Op. cit.* (1945).

tunately the discovery of *Arcticoceras henryi* (Meek and Hayden) in the basal 5 feet of the Stockade Beaver shale member furnishes an exact correlation with the Jurassic of Montana and Wyoming.

The Middle Jurassic age of the Gypsum Spring formation (Table I) of the Western Interior region is based (1) on its stratigraphic position below beds containing lower Callovian ammonites; (2) on the presence of gastropods resembling those in the Great Oölite of England; (3) on the occurrence near Cody, Wyoming, of ammonites probably identical with *Zemistephanus vancouveri* McLearn;[15] and (4) on its lateral gradation in Montana into the Sawtooth formation whose basal beds have furnished *defonticeras oblatum* (Whiteaves)[16] and whose upper silty beds are characterized by *Arctocephalites*.

The Gypsum Spring formation in the Black Hills area grades northward from a gypsiferous redbed facies into a gray shale-limestone-dolomite facies. This northward gradation is borne out by the subsurface sections in Fallon County, eastern Montana, and in Williams County, northwestern North Dakota. Thus, the Montana-Dakota Utilities Company's N. P. R. R. No. 1, in Sec. 17, T. 4 N., R. 62 E., on the Cedar Creek anticline, Fallon County, Montana, has a sequence of gypsiferous beds from about depths of 4,586 to 4,795 feet lying between the typical Sundance formation and the typical red sandstone and shale of the Spearfish formation.[17] These gypsiferous beds at the top include about 131 feet of red to green shale, anhydrite or gypsum and a little limestone. At the base they include about 68 or 78 feet of brown laminated limestone, maroon to green shale, and some anhydrite. Similarly the California Company's Kamp No. 1 in Sec. 3, T. 154 N., R. 96 W., Williams County, North Dakota,[18] has a sequence from depths of 5,315 to 5,585 feet which, from top to bottom, consists of about 45 feet of variegated shale and considerable sandstone, 190 feet of gray limestone and gray to black shale, and 35 feet of gypsum, limestone, and salmon-colored shale. Jurassic fossils have been reported from the limestone beds in this sequence as well as from limestone at a comparable stratigraphic position on the Cedar Creek anticline in eastern Montana.[19]

It seems reasonable to correlate the red and green shaly to sandy beds directly above the limestone part of these subsurface sections with the upper siltstone member of the Sawtooth formation, the upper redbed member of the Gypsum Spring formation in the northern part of the Big Horn Basin and southernmost

[15] F. H. McLearn, "Contributions to the Stratigraphy and Paleontology of Skidgate Inlet, Queen Charlotte Islands, B. C.," *Natl. Mus. Canada Contributions to Canadian Palaeontology Bull. 54, Geol. Ser. 49* (1929), p. 20, Pl. XI, Figs. 1, 2.

[16] McLearn, *op. cit.*, p. 16, Pl. XV, Fig. 1.

[17] Virginia H. Kline, *op. cit.*, p. 376.
C. T. Jones, *op. cit.*, pp. 130, 131.

[18] Virginia H. Kline, *op. cit.*, p. 372.
C. T. Jones, *op. cit.*, p. 130.
O. A. Seager *et al.*, "Discussion, Stratigraphy of North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), p. 1418.

[19] C. T. Jones, *op. cit.*, p. 131.

Montana, and with the time represented by the disconformity at the top of the Gypsum Spring formation in parts of the Wind River Basin and the Black Hills area. Likewise, it seems reasonable to correlate the gray shale and limestone part of these subsurface sections with the gray shale-limestone-dolomite facies in the northern part of the Black Hills, with the lithologically similar middle part of the Sawtooth formation of western Montana, and with the middle limestone-dolomite member of the Gypsum Spring formation at the outcrop in Wyoming and south-central Montana. The basal gypsiferous redbeds in these subsurface sections are probably correlative with part of the lower redbed member of the outcropping Gypsum Spring formation, although Hadley *et al.*,[20] point out that the lower redbed member is present only in the southern part of the structural basin lying north of the Pryor and Beartooth mountains in southernmost Montana. He ascribes its absence in the northern part of that basin immediately south of the Big Snowy and Little Belt mountains as due to non-deposition on the higher parts of the land surface over which the early Ellis sea advanced. To this viewpoint the writer agrees, considering that the basal member is fully developed locally at the northwest end of the Big Snowy Mountains. However, the lower redbed member is known to pass westward into marine beds in the lower part of the Sawtooth formation, and a similar change might be expected northward toward Canada, where the Jurassic seas probably persisted longer than in the Western Interior of the United States. Such a northward change is certainly suggested by the occurrence in the Bearpaw Mountains and the Sweetgrass Hills of dark marine shale and limestone characteristic of the Sawtooth formation, whereas nearly due south in central Montana gypsiferous redbeds are well developed at the same stratigraphic position.

Origin.—The Gypsum Spring formation of the Black Hills area was deposited in very shallow marine waters that were probably somewhat deeper toward the northwest end of the area than farther south as attested by a northward change from a gypsum-redbed sequence to a dolomite-limestone-gray shale sequence. It filled in an uneven erosion surface as indicated by its highly variable thickness within short distances, as well as by the conspicuous irregular upper surface of the Spearfish formation at many places. The absence of the Gypsum Spring formation in the southern part of the Black Hills is probably due both to original depositional thinning and to erosion at the end of Gypsum Spring time. However, the Nugget (?) sandstone is relatively considerably harder than the Spearfish formation and may have formed a low ridge bounding the Gypsum Spring sea on the south.

Erosion near the end of Gypsum Spring time is indicated by the peculiar pitted and polished pebbles at the base of the Stockade Beaver shale member of the Sundance formation. As these pebbles are identical with those in the lower part of the Nugget (?) sandstone exposed in the area west of Minnekahta, their source was probably that sandstone. Erosion of the sandstone most likely oc-

[20] *Op. cit.* (1945).

curred near the end of Gypsum Spring time, rather than earlier, considering that identical pebbles are widespread in central Wyoming[21] at the base of the "Lower Sundance" formation, but do not occur in the underlying Gypsum Spring formation. This does not mean that the contact between the Nugget sandstone and the Gypsum Spring formation is conformable, but implies that the Nugget sandstone was more extensively and deeply eroded near the end of Gypsum Spring time than earlier. Additional evidence of a widespread uplift of the sea bottom at the end of Gypsum Spring time is furnished by the occurrence of silty to sandy and locally pebbly beds at the top of the Sawtooth formation of Montana, which formation is correlative faunally and stratigraphically with the Gypsum Spring formation.

SUNDANCE FORMATION

The Sundance formation was first defined by Darton in 1899[22] for 60 to 400 feet of greenish shales, buff sandstones, and redbeds overlying the Spearfish formation and underlying the Morrison formation, then called Beulah shales, or locally underlying the Unkpapa sandstone. He reviewed the previous publications on the Jurassic of the Black Hills and described the characteristics of the Jurassic at various localities. Subsequently the Sundance formation was described by Darton and his associates in various Government reports dealing with the Black Hills area.[23] Most of this information was summarized, the subdivisions of the Sundance formation differentiated, and many sections redescribed by Darton in 1909 and 1925.[24] In none of these publications was a type section designated for the Sundance formation, although Darton and O'Harra[25] in their description of the Belle Fourche Quadrangle stated, "The type locality is above Sundance, not far southeast of this quadrangle."

[21] Love, *op. cit.* (1945).

[22] N. H. Darton, "Jurassic Formations of the Black Hills of South Dakota," *Bull. Geol. Soc. America*, Vol. 10 (1899), pp. 387–93.

[23] N. H. Darton, ". . . Geology and Water Resources of the Southern Half of the Black Hills and Adjoining Regions in South Dakota and Wyoming," *U. S. Geol. Survey Ann. Rept.*, Vol. 21, Pt. 4 (1901), pp. 520–24.

———, "Description of the Oelrichs Quadrangle," *U. S. Geol. Survey Atlas, Oelrichs Folio 85* (1902), p. 3.

———, "Description of the Newcastle Quadrangle," *U. S. Geol. Survey Atlas, Newcastle Folio 107* (1904), pp. 3, 4.

———, "Description of the Sundance Quadrangle," *ibid., Sundance Folio 127* (1905), p. 3.

——— and W. S. T. Smith, "Description of the Edgemont Quadrangle," *ibid., Edgemont Folio 108* (1904), p. 4.

——— and C. C. O'Harra, "Description of the Aladdin Quadrangle," *ibid., Aladdin Folio 128* (1905), pp. 2, 3.

———, "Description of the Devils Tower Quadrangle," *ibid., Devils Tower Folio 150* (1907), p. 2.

———, "Description of the Belle Fourche Quadrangle, South Dakota," *ibid., Belle Fourche Folio 164* (1909), p. 3.

[24] "Geology and Water Resources of the Northern Portion of the Black Hills and Adjoining Regions in South Dakota and Wyoming," *U. S. Geol. Survey Prof. Paper 65* (1909), pp. 31–37.

"Central Black Hills," *U. S. Geol. Survey Atlas, Central Black Hills Folio 219* (1925), pp. 10, 11.

[25] *Op. cit.* (1909), p. 3.

The writer examined outcrops of the Sundance formation near Sundance, which is actually 18 miles southwest of the Belle Fourche Quadrangle, and was unable to find any outcrop, or closely associated outcrops, adequate to serve as a type section. The best exposures are on the main highway about two miles west of Sundance, but can not be measured accurately. A section could be fitted together from partial exposures in the general area from 9 to 12 miles south-southwest of Sundance. However, as this is some distance from Sundance, it seems preferable not to designate any section as type but instead to select one of the best exposed, most complete, and most accessible sections in the Black Hills as a standard of reference. These conditions are fulfilled by a section near Spearfish, which may be described as follows.

SUNDANCE AND GYPSUM SPRING FORMATIONS ONE MILE NORTH-NORTHEAST OF CENTER OF SPEARFISH IN SEC. 3, T. 6 N., R. 2 E., LAWRENCE COUNTY, SOUTH DAKOTA

	Feet
Morrison formation	
Mostly covered. Basal beds consist of fine-grained, pseudo-oölitic, yellow sandstone	
Sundance formation	
Redwater shale member	
Shale, dark gray, fissile, contains some very thin beds of fine-grained, greenish gray sandstone	15
Limestone, shaly, and sandy shale, fossiliferous	8
Shale, dark gray; some silty beds in lower 25 feet; belemnites abundant	65
Sandstone, yellow, soft	2
Shale, dark gray	11
Sandstone, yellow, soft	2
Shale, greenish gray, silty	7
Sandstone, gray, soft, glauconitic	½
Total thickness of Redwater shale member	110+
Lak member	
Sandstone, fine-grained, and siltstone, mostly maroon; some greenish layers and spots; weathers light pink	60
Hulett sandstone member	
Sandstone and silty shale, soft, yellowish gray	17+
Shale, silty, greenish gray	6
Sandstone, fine-grained, mostly yellow, some pinkish	4
Shale, silty, and siltstone, light red and yellowish, weathering pinkish	11
Shale, sandy, greenish gray to pinkish; some pink shaly sandstone	12
Sandstone, thick- to medium-bedded, mostly pink to yellow, fine-grained, ripple-marked, glauconitic	6
Shale, greenish gray, partly sandy, poorly exposed	12
Sandstone, thick- to medium-bedded, mostly pink to yellow, fine-grained, ripple-marked, glauconitic	29
Total thickness of the Hulett sandstone member	97
Stockade Beaver shale member	
Shale, soft, brownish gray in lower 15 feet, dark gray above; weathers yellowish gray; a few pitted pebbles of a very dense metamorphic rock in basal foot	60
Total thickness of Sundance formation	327+
Gypsum Spring formation	
Gypsum, bedded, white, sugary	1
Shale, yellowish gray, soft	2
Shale, maroon, several inches of gypsum at top	3
Gypsum, white; fresh exposure is fairly compact, weathered surface is sugary	2

Shale, mostly maroon, some green, weathering pink; includes several beds of white gypsum from 2 to 8 inches thick; red color somewhat lighter than in underlying Spearfish formation	7
Gypsum, bedded, white; fresh exposure compact, weathered surface sugary; rests on highly irregular surface of Spearfish formation	10–30
Total thickness of Gypsum Spring formation	25–45

The Sundance formation of the Black Hills area as herein defined consists, from bottom to top, of the Canyon Spring sandstone member, Stockade Beaver shale member, Hulett sandstone member, Lak member, and Redwater shale member. Darton recognized and described these five members as lithologic units but did not name them. He placed the Gypsum Spring formation in the top of the Spearfish formation[26] on the basis of lithologic resemblances just as similar beds in Wyoming and Montana have until recently been placed in the top of the Chugwater formation. The application of names to these units is justified (1) by their correlation with units of formational rank elsewhere in the Western Interior, (2) by their fairly well defined boundaries, which will permit mapping when desirable economically, (3) for the sake of convenience in discussing geologic history and correlation, and (4) in order to emphasize that the Jurassic sequence is much more complete and more complicated than generally realized.

There remains the problem whether the Unkpapa sandstone overlying the Redwater shale member is a facies of the Sundance formation or of the Morrison formation. As described by Darton,[27] the Unkpapa sandstone consists of white, yellow, buff, or purple, fairly soft, fine-grained, generally massive sandstone. It is well developed along the eastern side of the Black Hills but attains its greatest thickness of 50 to 225 feet at the southeastern end between Cascade Springs and Buffalo Gap where the Morrison formation is absent. Its thickness diminishes north of Buffalo Gap but ranges from 30 to 150 feet as far as Sturgis and the unit is traceable to Whitewood. From the area of Hermosa northward it underlies the Morrison formation. Along the northern, western, and southern sides of the Black Hills the Unkpapa sandstone is either absent or is represented locally by a thin yellowish sandstone which Darton provisionally included in the top of the Sundance formation. The thickness of this sandstone is generally only a few feet, but in the area near the Belle Fourche River and north of Devils Tower ranges from 10 to 30 feet.

The writer considers that the Unkpapa sandstone is most probably a facies of the Morrison formation, because it thickens as the Morrison thins, attains its greatest thickness where the Morrison is absent, and its presence has no apparent relationship to the thickness of the underlying Redwater shale member. Furthermore, recent studies by Love and others[28] in the Wind River Basin of central

[26] *Op. cit.* (1909), pp. 28, 29.

[27] *Op. cit.* (1899), p. 393; (1909), p. 37.

[28] J. D. Love and others, "Stratigraphic Sections and Thickness Maps of Jurassic Rocks in Central Wyoming," *U. S. Geol. Survey Prelim. Chart 14*, Oil and Gas Investig. Ser. (1945).

Wyoming demonstrate that the Morrison formation of that area may change completely from a sandy clay facies to a massive white sandstone facies in a distance of less than 20 miles. In contrast, the highest marine Jurassic beds of the Western Interior region show rather gradual lithologic changes.

The subsurface extent and character of the various members of the Sundance formation would require a special study, as published records are inadequate. In South Dakota the Sundance formation extends eastward at least as far as the Missouri River[29] and includes rocks similar to exposures in the Black Hills. In North Dakota the Sundance formation, or equivalent beds, has been identified at least in Williams, Renville, and Kidder counties in the western part of the state[30] and probably occur farther east, because a well in south-central Manitoba, Canada, contains fossiliferous Jurassic, including 140 feet of gypsiferous beds resting on Devonian rocks.[31] At least the Gypsum Spring formation and Stockade Beaver shale member of the Sundance formation seem to be represented in this well at depths of 900 to 1,110 feet. Perhaps the overlying members of the Sundance formation are represented by part of the beds questionably assigned to the Lower Cretaceous.

The section of marine Jurassic in the California Company's Kamp well No. 1, in Sec. 3, T. 154 N., R. 96 W., Williams County, North Dakota,[32] appears to be similar to that in the Black Hills except that the Gypsum Spring formation is much thicker and more calcareous. The Jurassic section on the Cedar Creek anticline in southeastern Montana[33] is likewise similar but does not appear to have redbeds representing the Lak member of the Sundance formation.

CANYON SPRINGS SANDSTONE MEMBER

Definition.—The Canyon Springs sandstone member of the Sundance formation comprises a basal marine sandstone locally including some red to gray shale and attaining 30 to 45 feet in thickness. The type locality is designated as a

[29] E. P. Rothrock and T. R. Robinson, Jr., "Artesian Condition in West-Central South Dakota," *South Dakota Geol. Survey Rept. of Investig. 26* (1936), pp. 26, 27.
Norval Ballard, "Regional Geology of Dakota Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), pp. 1562, 1563, 1579–81.

[30] C. T. Jones, "Contributions to Stratigraphy of Northern Great Plains Area," *Kansas Geol. Soc. Guidebook 14th Ann. Field Conf.* (1940), pp. 130, 131.
Virginia H. Kline, "Stratigraphy of North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), pp. 369, 371, 372.
O. A. Seager *et al.*, "Discussion, Stratigraphy of North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), p. 1418.

[31] R. T. D. Wickenden, "Paleozoic and Jurassic Formations in Well Sections in Manitoba," *Canada Geol. Survey Summ. Rept. 1933, Pt. B.*, Pub. 2353 (1934), pp. 158–68.
V. H. Kline, *op. cit.*, p. 365.
Norval Ballard, *op. cit.*, pp. 1572, 1580, 1581.
G. S. Hume, "Petroleum Geology of Canada," *Canada Dept. Mines and Res. Geol. Survey Bull. 98, Geol. Ser. No. 54* (1944), p. 23.

[32] Virginia H. Kline, *op. cit.*, pp. 371, 372.

[33] Virginia H. Kline, *op. cit.*, p. 376.
O. A. Seager, "Test on Cedar Creek Anticline, Southeastern Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), p. 863.

conical butte about 4 miles west of Horton, Wyoming, ¼ mile north of the road from Horton to Upton, and near the center of Sec. 23, T. 48 N., R. 62 W. The type section consists of about 26 feet of soft, fine-grained, calcareous, fossiliferous white sandstone that is well exposed on the south slope of the butte. At this place the member rests sharply on 10 to 20 feet of massive white gypsum belonging to the Gypsum Spring formation and is overlain abruptly by calcareous gray shale belonging to the Stockade Beaver shale member of the Sundance formation. The top of the butte is capped with the Hulett sandstone member. Near the northern end of the butte the exposures are less perfect but the Canyon Springs sandstone member appears to be about 35 feet thick and has about 12 feet of reddish to greenish sandstone at the top above massive white sandstone. The member is named after the Canyon Springs Prairie immediately east of the type locality.

Stratigraphic and lithologic features.—The Canyon Springs sandstone member ranges from a feather-edge to about 45 feet in thickness, thickens and thins considerably within short distances, and is recognizable as a member only along the southern and western margins of the Black Hills. If present along the eastern and northern margins of the Black Hills between Rapid City and Alva, it must be represented by a few inches of yellowish gray sandstone or a thin conglomerate consisting of chert-like pebbles, or uncommonly of quartz pebbles. The member consists mainly of fossiliferous grayish white to white sandstone that is slightly calcareous, is mostly fine-grained but includes many coarse grains, in places many red specks, and may be oölitic near the top. This white sandstone may pass laterally or vertically into yellowish or salmon-colored sandstone and may include locally some units of maroon to gray shale.

One of the thickest and best exposures of the member in the southeastern part of the Black Hills is on Beaver Creek about 2 miles northwest of Buffalo Gap and may be described as follows.

CANYON SPRINGS SANDSTONE MEMBER ON BEAVER CREEK IN SEC. 13, T. 6 S., R. 6 E., CUSTER COUNTY, SOUTH DAKOTA

	Feet
4. Shale, mostly maroon, some gray	13
3. Sandstone, massive, soft, cross-bedded, salmon-colored	12
2. Shale, maroon at base, becoming gray upward, some thin beds of yellowish gray sandstone in upper 5 feet. *Trigonia conradi* Meek and Hayden obtained from upper foot	10
1. Sandstone, gray, hard, rests on red shale of Spearfish formation	5
	40

Between Buffalo Gap and Rapid City the Canyon Springs sandstone member ranges from 25 to 3 feet, or less, in thickness and is mostly of buff to gray color. Near Hot Springs the member is mostly buff to salmon-colored and ranges from 6 to 25 feet in thickness. Near Sheps Canyon about 7 miles south of Hot Springs it attains 45 feet in thickness and is cliff-forming, as illustrated by Darton.[34] About 1½ miles north of Cascade Springs along the west side of Alabaugh Canyon the member is about 35 feet thick and consists from base to top of about 17 feet

[34] *Op. cit.* (1902), p. 3, Fig. 8.

of massive, white, fine-grained, calcareous sandstone, 13 feet of light yellow, calcareous sandstone that becomes purplish at the top and has fossils in its upper foot, and then 5 feet of purplish shale underlying the typical Stockade Beaver shale member.

Excellent exposures of the Canyon Springs sandstone member occur in an area extending from 2 to 7 miles west-northwest of Minnekahta. Three miles west-northwest of Minnekahta on a northward-projecting spur, the member consists of about 13 feet of white, fine-grained sandstone, characterized by red specks, and containing some oysters. It is underlain by salmon-colored sandstone, provisionally assigned to the Nugget (?) sandstone, and overlain abruptly by the Stockade Beaver shale member. About 7 miles west-northwest of Minnekahta in Sec. 6, T. 7 S., R. 3 E., a high bluff composed mainly of Nugget (?) sandstone is capped with apparent disconformity by about 3 feet of slightly oölitic, fossiliferous, white sandstone that represents the Canyon Springs sandstone member. Westward from this locality the member overlaps within a few miles onto the Spearfish formation but persists as a foot or more of white sandstone at least as far west as Pass Creek about 23 miles west of Minnekahta. An interesting outcrop of the member occurs just west of Pass Creek (Hell Canyon) in the NE. ¼ of Sec. 10, T. 6 S., R. 1 E., about 3 miles northeast of Dewey and 100 yards north of the road to Dewey. The outcrop nearest the road consists of about 5 feet of fossiliferous, fine-grained, white sandstone resting on the Spearfish formation and overlain by a similar thickness of maroon and gray shale below the typical gray shale of the Stockade Beaver shale member. Traced northward another 100 yards, the white sandstone persists, the maroon shale disappears, and the base of the overlying Stockade Beaver shale member contains pitted and polished, dark gray, chert-like pebbles. Then abruptly the white sandstone thickens to at least 25 feet, filling pronounced local hollows in the Spearfish formation. A quarter of a mile farther north, the white sandstone thins to about 10 feet and is fairly fossiliferous.

The Canyon Springs sandstone member was not traced continuously northward, but on the east side of Elk Mountain in the S. ½ of Sec. 2, T. 7 N., R. 1 E., about 15 miles southeast of Newcastle, it is probably represented by a foot of white sandstone overlying 4½ feet of white gypsum that is the southernmost extension of the Gypsum Spring formation. Farther north the member is missing on Elk Mountain and on Stockade Beaver Creek, but is locally well developed at several places between the head of Oil Creek and Sundance. It is possibly represented near Hulett by some sandstone layers that the writer places in the lower part of the Stockade Beaver shale member because they contain much clayey material and are intimately interbedded with many thin layers of shale.

The Canyon Springs sandstone member rests on the Gypsum Spring formation at the type locality west of Horton and apparently locally along the east side of Elk Mountain. It rests on a massive sandstone interpreted as Nugget sandstone in an area extending from 2 to 7 miles west-northwest of Minnekahta. In most places it rests on the Spearfish formation. The contact with these for-

mations is disconformable as shown by overlap relationships, as in the area west of Minnekahta, and by local pronounced channeling, as shown near Pass Creek. It seems probable that the time break between the Gypsum Spring formation and the Canyon Springs sandstone member is very small, although the absence of the Gypsum Spring formation locally within its area of outcrop, as in Sec. 32, T. 50 N., R. 63 W., about 9 miles southwest of Sundance, might be interpreted as due to erosion.

The upper contact of the Canyon Springs sandstone member with the Stockade Beaver shale member is generally fairly abrupt. In the southeastern part of the Black Hills the upward change is from soft maroon shale, or buff to salmon-colored sandstone to fossiliferous gray shale; in the southwestern and western parts from white sandstone to gray shale. This lithologic change is not interpreted as a disconformity, as the faunas in the two members are essentially the same, but rather reflects the local source of the sandstone and the rapid advance of the sea far beyond the Black Hills area.

Correlation.—The Canyon Springs sandstone member of the Sundance formation contains specimens of *Ostrea strigilecula* White and *Eumicrotis curta* (Hall) at many places, but only the upper few feet of the type section have furnished many species which may be listed as follows.

Arcticoceras cf. *A. henryi* (Meek and Hayden)
Arcticoceras n. spp.
Pleuromya subelliptica (Meek and Hayden)
Pholadomya aff. *P. inaequiplicata* Stanton
Pholadomya cf. *P. kingi* Meek
Quenstedtia arcuata (Meek and Hayden)
Quenstedtia sp.
Corbicellopsis? sp.
Camptonectes cf. *C. platessiformis* White
Eumicrotis curta (Hall)
Pinna sp.
Ostrea strigilecula White
Volsella sp.
Lima sp.
Trigonia cf. *T. americana* Meek
Trigonia cf. *T. montanaensis* Meek
Lingula sp.

Among the pelecypods listed, *Ostrea strigilecula* and *Eumicrotis curta* are long-ranging; most of the others have been found in the Stockade Beaver shale member in the Black Hills area and in the Rierdon formation of Montana. Species of *Pholadomya* and *Trigonia* comparable with the species listed occur in both the Sawtooth formation and the Rierdon formation. Greater reliance may be placed on the ammonite *Arcticoceras* which is represented by three species similar to, or identical with, species in the basal beds of the Rierdon formation and in the Stockade Beaver shale member, and are unlike the *Arctocephalites* in the upper siltstone member of the Sawtooth formation of western Montana. Correlation of the latter with the Canyon Springs sandstone member might seem logical on the basis of stratigraphic position but can not be maintained faunally. Besides, the silt-

stone member of the Sawtooth formation grades downward into the underlying beds and is sharply separated from the Rierdon formation; whereas the Canyon Springs sandstone member of the Sundance formation rests sharply on the Gypsum Spring formation and appears to be conformable with the overlying beds. Thus the siltstone member of the Sawtooth formation appears to have been deposited during a retreat of the Middle Jurassic sea at the end of Gypsum Spring-Sawtooth time, whereas the Canyon Springs sandstone member was deposited during an advance of the sea in earliest Upper Jurassic time. The age of the Canyon Springs sandstone member and the Stockade Beaver shale member appears to be essentially the same.

Origin.—The Canyon Springs sandstone member was deposited in earliest Sundance time as a basal marine sand that filled in the irregularities of an eroded surface. This is shown by its conformable relationship with the overlying Stockade Beaver shale member, by its overlap across several formations, and by its rather abrupt thickening and thinning. It probably represents a reworked residual sand, rather than being derived from a distant source, because where it is typically developed the lower part of the Stockade Beaver shale member contains very little sandstone. The most likely source appears to have been the Nugget (?) sandstone exposed at the southern end of the Black Hills and present to the southwest in Wyoming. Perhaps the absence of the Nugget (?) sandstone farther north explains the absence or thinness of sandstone at the base of the Sundance formation along the northern and northeastern margins of the Black Hills.

STOCKADE BEAVER SHALE MEMBER

Definition.—The Stockade Beaver shale member of the Sundance formation includes about 50 feet of medium to dark gray, soft, fissile, calcareous shale lying directly below the Hulett sandstone member of the Sundance formation in the Black Hills area. Its upper contact is gradational within a few feet. Its lower contact with the Canyon Springs sandstone member is fairly abrupt but apparently conformable. Locally it rests directly on the Gypsum Spring formation or on the Spearfish formation. The type section is designated as on the west side of Stockade Beaver Creek about 5 miles northeast of Newcastle in Sec. 18, T. 45 N., R. 60 W., Wyoming, where the member is 63 feet thick and rests on a 12-foot ledge of white gypsum.

Stratigraphic and lithologic features.—The Stockade Beaver shale member ranges in thickness from about 5 to 85 feet and averages about 50 feet (Figs. 2 and 3). Along the southern and central parts of the Black Hills, including the type locality, it is highly calcareous, moderately fossiliferous, commonly contains limestone nodules in its lower 10 feet, and contains some sandstone and limonitic nodules in its basal foot. Northward it becomes less calcareous, less fossiliferous, acquires minor amounts of soft, greenish gray to yellowish gray siltstone and sandstone, and becomes slightly gypsiferous. Pitted, polished, subangular pebbles of a hard, dark gray metamorphic, chert-like rock ranging from $\frac{1}{4}$ to several

inches in diameter have been found at the base of the member near Minnekahta, near Pass Creek 3 miles northeast of Dewey, and near Spearfish. Quartzite pebbles of comparable size occur locally at the base of the member in the northern part of the Black Hills southwest of Aladdin, northwest of Beulah, and near Redwater Creek from 7 to 9 miles northwest of Spearfish. The contact with the overlying Hulett sandstone member is gradational, but it is defined as the point where slabby, ripple-marked sandstones predominate over soft gray, fissile shale and can generally be picked within several feet. The lower contact with the Canyon Springs sandstone member is fairly abrupt and probably not disconformable as the two members contain essentially the same fossils. The contact with the Gypsum Spring formation is sharp and disconformable.

The following section one mile southwest of Hulett illustrates the silty and sandy characteristics of the member in the northern part of the Black Hills.

LOWER PART OF JURASSIC SEQUENCE ONE MILE SOUTHWEST OF HULETT IN ROAD CUT ON EAST SIDE OF HIGHWAY IN SW. ¼ OF SEC. 12, T. 54 N., R. 65 W., CROOK COUNTY, WYOMING

	Feet
Sundance formation (part)	
Hulett sandstone member (incomplete)	
15. Sandstone, massive, yellowish, gray, glauconitic	30+
Stockade Beaver shale member	
14. Shale and sandy shale interbedded, grading into overlying sandstone	8
13. Shale, dark gray to yellowish gray, partly silty, interbedded every few feet with 2 to 3 inch layers of fine-grained yellow sandstone	18
12. Shale, dark gray to yellowish gray, partly silty	6
11. Sandstone, yellow, very fine-grained, interbedded with much yellowish gray shale. U.S.G.S. Mes. loc. 19563 at top contains *Eumicrotis curta* (Hall) and *Trapezium* cf. *T. subequalis* Whitfield	5
10. Shale, yellowish gray, soft, much selenite	13
9. Shale, chunky, calcareous, gray, contains thin beds of very fine-grained sandstone	7
8. Shale, dark gray, soft, some sandy shale near top	7
7. Shale and sandy shale, gray, interbedded with thin beds of soft, yellow sandstone	5
6. Shale, dark gray, soft, much selenite	2
5. Sandstone, yellow, and gray shale interbedded in very thin beds	3
4. Shale, dark gray, soft	2
3. Sandstone, yellow soft, some very thin layers of gray shale	4
2. Shale, dark gray, soft	3
Total thickness of Stockade Beaver shale member	83
Gypsum Spring formation	
1. Limestone, dolomitic and dolomite, white, thin-bedded to shaly, in part interbedded with calcareous shale, upper layers contain *Gryphaea*, *Ostrea*, and *Camptonectes*, dolomitic beds near base contain irregularly shaped pieces of dark chert and rest sharply on redbeds of the Spearfish formation	14

Correlation.—The Stockade Beaver shale member of the Sundance formation is correlative basally with the basal part of the Sundance formation of north-central Wyoming, the "Lower Sundance" of central Wyoming, and the Rierdon formation of Montana, as its lower 5 to 20 feet have furnished the ammonite *Arcticoceras henryi* (Meek and Hayden) and related species (Table I). *Arcticoceras* has been found in the gorge two miles west of Cody, Wyoming, in a 4-foot bed of nodular to shaly limestone, whose base is 7 feet above the top of the Gypsum

Spring formation. About 4 feet higher a similar bed has furnished certain species of *Gowericeras* and *Cadoceras* that are widespread in Montana in the lower part of the Rierdon formation. *Arcticoceras* has been found in Montana in the Little Rocky Mountains, in Cinnabar Mountain near Gardner, and at several localities in the Sawtooth Range in the basal beds of the Rierdon formation a little below the beds characterized by *Gowericeras*. In the Sawtooth Range it occurs just above the Sawtooth formation, whose highest silty member is characterized by coarsely ribbed species of *Arctocephalites*. Interestingly, this same faunal succession occurs in East Greenland.[35] Apparently the species of *Arcticoceras* represent a consistent, well defined faunal zone. However, *Arcticoceras henryi* is not the most common species and should not be made the zonal index.

The lower part of the Stockade Beaver shale member contains a fair number of fossils, including many of the Jurassic species from the Black Hills area originally described by Meek and Hayden.[36] Two miles east-southeast of Minnekahta the upper 48 feet of the Stockade Beaver shale member have furnished the following fossils (U.S.G.S. Mes. loc. 19555).

Lingula brevirostris Meek and Hayden
Eumicrotis curta (Hall)
Pleuromya subelliptica (Meek and Hayden)
Tancredia cf. *T. warrenana* Whitfield
Corbicellopsis? inornata (Meek and Hayden)
Pachyteuthis sp.

The next lower 6 feet bear thin beds of nodular limestone which contain the following (U.S.G.S. Mes. loc. 19556).

Arcticoceras henryi (Meek and Hayden)
Arcticoceras n. sp.

About 3 miles west-northwest of Minnekahta the lower 5 feet of the Stockade Beaver shale member contains the following (U.S.G.S. Mes. loc. 19558).

Eumicrotis curta (Hall)
Astarte? fragilis Meek and Hayden
Corbicellopsis? inornata (Meek and Hayden)
Quenstedtia sublevis (Meek and Hayden)

The overlying 43 feet of shale at the same locality have furnished the following (U.S.G.S. Mes. loc. 19559).

Pentacrinus asteriscus Meek and Hayden
Ostrea sp.
Camptonectes extenuatus (Meek and Hayden)
Eumicrotis curta (Hall)
Eumicrotis orbiculata (Whitfield)
Pleuromya subelliptica (Meek and Hayden)
Corbicellopsis? inornata (Meek and Hayden)

On the east side of Elk Mountain about 2 miles south of the triangulation

[35] L. F. Spath, "The Invertebrate Faunas of the Bathonian-Callovian Deposits of Jameson Land, East Greenland)," *Meddelelser om Grønland*, Bd. 87, Nr. 7 (1932), pp. 138, 145.

[36] F. B. Meek and F. V. Hayden, "Palaeontology of the Upper Missouri Invertebrates," *Smithsonian Contr. to Knowledge*, No. 14, Art. 5 (172) (1865), pp. 66–128, Pls. III to V.

station and 15 miles southeast of Newcastle the basal 5 feet of the Stockade Beaver shale member contain the following (U.S.G.S. Mes. loc. 19560).

Ostrea strigilecula White
Eumicrotis curta (Hall)
Corbicellopsis? inornata (Meek and Hayden)
Quenstedtia sublevis (Meek and Hayden)
Arcticoceras cf. *A. henryi* (Meek and Hayden)

On the east side of Elk Mountain due east of the triangulation station the basal 5 feet of the Stockade Beaver shale member contain the following (U.S.G.S. Mes. loc. 19561).

Ostrea strigilecula White
Gryphaea cf. *G. nebrascensis* Meek and Hayden
Camptonectus extenuatus (Meek and Hayden)
Eumicrotis curta (Hall)
Pleuromya subelliptica (Meek and Hayden)
Tancredia cf. *T. warrenana* Whitfield
Corbicellopsis? inornata (Meek and Hayden)
Quenstedtia sublevis (Meek and Hayden)
Arcticoceras henryi (Meek and Hayden)

The middle and upper parts of the Stockade Beaver shale member above the beds with *Arcticoceras* have not furnished many species but include *Eumicrotis curta* (Hall), *Camptonectes* sp., *Trapezium* cf. *T. subequalis* Whitfield, *Pachyteuthis*, and *Graphaea nebrascensis* Meek and Hayden. Interestingly the beds with *Arcticoceras* contain only one *Gryphaea* fragment that can be compared with *G. nebrascensis*, whereas the overlying shales contain a few specimens characteristic of the species. This situation is comparable with that in Montana and Wyoming, where *G. nebrascensis* first appears in abundance in the beds characterized by *Gowericeras*, although it occurs rarely in older beds. The comparison suggests that the middle, and perhaps the upper part, of the Stockade Beaver shale member represents the *Gowericeras* zone.

In North Dakota the correlative of the Stockade Beaver member may occur at depths of 5,205 to 5,315 feet in the California Company's Kamp No. 1, Williams County. The beds at these depths are described[37] as greenish gray to dark gray shale, black to tan limestone, calcareous sandstone, and some gypsum. They overlie a sequence that may be equivalent to the Gypsum Spring formation, as discussed previously. In eastern Montana on the Cedar Creek anticline about 125 feet of greenish shale and much limestone, containing some sandy material basally, appear to occupy the same stratigraphic position as the Stockade Beaver shale.[38]

Origin.—A widespread gentle uplift of the sea bottom at the end of Gypsum Spring time was followed very shortly by incursions of marine waters over considerable areas, giving rise to soft, gray, calcareous shales containing normal marine organisms. In some areas erosion of the Nugget (?) sandstone, or similar rocks, had produced some loose sands that were reworked and swept into hollows

[37] Virginia H. Kline, *op. cit.*, p. 372.

[38] *Ibid.*, p. 376.

on the sea floor, leaving concentrations of pebbles locally which were incorporated in the base of the shales. Discounting these basal pebbly and sandy beds the main source of the clastic sediment during Stockade Beaver time was toward the east or southeast, as the member is less calcareous and contains more silty and sandy material than the Rierdon formation of Montana or the lower part of the Sundance formation of the Big Horn Basin of north-central Wyoming. This agrees with recent studies in central Wyoming, which show that the "Lower Sundance" thins and becomes sandy toward the east and southeast.[39] The near disappearance of the Stockade Beaver shale member in the southeastern part of the Black Hills near Hot Springs and Buffalo Gap may mean that it is thinning out by overlap in that direction, or passing laterally into sandstone, or may reflect a disconformity at its base.

HULETT SANDSTONE MEMBER

Definition.—The Hulett sandstone member of the Sundance formation includes 25 to 120 feet of marine sandy beds consisting mainly of grayish, moderately hard, thin- to thick-bedded, fine-grained, calcareous, glauconitic, ripple-marked sandstone. It grades into the underlying gray Stockade Beaver shale member and into the overlying maroon sandstone and siltstone of the Lak member of the Sundance, but the contacts can be selected within a few feet. The type section is designated as on the north side of Bush Canyon about 2½ miles north of Hulett, Wyoming, in Secs. 25 and 36, T. 55 N., R. 65 W.

Stratigraphic and lithologic features.—The Hulett sandstone member is generally well exposed (Figs. 2 and 3). Along the southeastern and southern margins of the Black Hills it ranges in thickness from about 25 to 55 feet and is characterized by hard, micro-glauconitic, yellowish to greenish gray, thin-bedded, slabby sandstone interbedded with considerable gray to greenish gray, sandy shale. Sandstone predominates in the lower part of the member and locally forms low cliffs. Northward the Hulett sandstone member thickens in an irregular manner to about 120 feet along Redwater Creek at the north end of the Black Hills. This thickening is accompanied by changes in the sandstone layers, which become harder, more massive, and lighter in color. Along the northwestern margin of the Black Hills in the area between Hulett and Spearfish the middle part of the Hulett sandstone member forms conspicuous cliffs that are light yellow, or pinkish, or less commonly white, and weather light buff. The silty to sandy shale layers are mostly yellowish to greenish gray and generally darker than the sandstone. In most sections the upper 10 to 30 feet of the member consists of relatively soft marine shale and sandstone that form a marked recess above bluffs of massive sandstone. The member is characterized throughout the Black Hills by numerous oscillation ripple-marks from 2 to 3 inches across.

Various sections of the Hulett sandstone member are described at the end of this paper. The type section in the north side of Bush Canyon 2½ miles north of Hulett, is as follows.

[39] Love *et al.*, *op. cit.* (1945).

		Feet
3.	Sandstone, thin-bedded to shaly, interbedded with sandy shale, yellowish gray, glauconitic	13
2.	Sandstone, thick-bedded, ripple-marked, fine-grained, light yellow to pink, forms cliffs about 40 feet high	57
1.	Shale, gray, sandy, interbedded with 2- to 8-inch beds of fine-grained, ripple-marked, yellow sandstone	12
	Total thickness	82

Correlation.—The Hulett sandstone member is not very fossiliferous. *Pentacrinus asteriscus* Meek and Hayden was noted near the middle of the member 2 miles east-southeast of Minnekahta. Fragments of *Camptonectes* were found near the base of the member on Stockade Beaver Creek. The best collection was obtained 22 feet above the base of the member on Beaver Creek, 2 miles northwest of Buffalo Gap, and consists of the following species (U.S.G.S. Mes. loc. 19566).

Quenstedtia arcuata (Meek and Hayden)
Q. aequilateralis (Meek and Hayden)
Quenstedtia n. sp. aff. *Q. postica* (Whitfield)
Quenstedtia n. sp.

The ranges of the various species of *Quenstedtia* are not known well enough to permit close correlations with the Jurassic beds of Wyoming or Montana. Personally, the writer prefers to correlate the Hulett sandstone member with the *Kepplerites* (*Seymourites*) beds at the top of the Rierdon formation in Montana on the basis that the middle and upper parts of the Stockade Beaver shale member seem to represent the *Gowericeras* beds as discussed previously (Table I).

The Hulett sandstone member of the Black Hills is similar lithologically and stratigraphically to the gray, calcareous, fine-grained sandstone in the upper part of the "Lower Sundance" in the Wind River Basin of central Wyoming.[40] Correlation of these two sandstones is justified by the fact that they are both underlain by calcareous, gray shales which are of the same age basally.

Marine sandstone at a similar stratigraphic position occurs in the eastern part of the Big Horn Basin, but has not been observed at outcrops in Montana. The Hulett may be present in easternmost Montana, as 69 feet of fine-grained, light gray sandstone and some greenish shale have been recorded[41] at depths of 4,392 to 4,461 feet in the Montana-Dakota Utilities Company's N.P.R.R. No. 1 in Sec. 17, T. 4 N., R. 62 E., Fallon County. These sandstone beds overlap shales which are similar to the shales of the Stockade Beaver member.

Bartram[42] considers that the beds herein called Hulett sandstone member and Lak member belong in one member which he correlates with the Entrada sandstone of Wyoming, Colorado, and Utah. The Hulett sandstone member, however, differs by being marine, glauconitic, mainly gray to yellow instead of maroon, and its sandy sediments most probably were derived from the east or southeast.

[40] Love *et al.*, *op. cit.* (1945).

[41] Virginia H. Kline, *op. cit.*, p. 376.

[42] John C. Bartram, "The Stratigraphy and Structure of Eastern Wyoming and the Black Hills Area," *Fourteenth Annual Field Conference of the Kansas Geological Society* (1940), p. 117.

Origin.—An easterly source for the sands of the Hulett sandstone member is indicated by its probable correlation with the shales in the upper part of the Rierdon formation in Montana and with somewhat less sandy beds in the Big Horn Basin. A westerly source after Rierdon time would imply that the sands were either completely removed from most of Montana prior to deposition of the Swift formation, or that those areas were land during deposition of the Hulett sandstone member. These possibilities seem unlikely, particularly since recent studies show[43] that the sandstones in the upper part of the "Lower Sundance" of central Wyoming become coarser and even pebbly toward the southeast.

LAK MEMBER

Definition.—The Lak member of the Sundance formation is herein defined for 25 to 100 feet, or more, of dominantly red, fine-grained sandstone and siltstone overlying gradationally the cliff-forming Hulett sandstone member and underlying sharply the glauconitic Redwater shale member. The type section is designated as on the west side of Stockade Beaver Creek about 5 miles northeast of Newcastle, Wyoming, in Sec. 18, T. 45 N., R. 60 W. At this place the Lak member consists of at least 80 feet of soft maroon sandstone and siltstone including a 2-foot bed of greenish gray siltstone 15 feet below the top. The member is named after the Lak reservoir on the L.A.K. Ranch. The reservoir is located about 3 miles south of the type section. The member does not crop out at the reservoir although undoubtedly present beneath alluvium. The name Lak was selected as representing the most appropriate geographic feature near a well exposed, easily accessible section which is also the type section for the Stockade Beaver shale member.

Stratigraphic and lithologic features.—The thickness of the Lak member changes considerably within short distances, but the range in thickness does not appear to be any greater in one part of the Black Hills than in another (Figs. 2 and 3). The member consists mainly of unfossiliferous, homogeneous, poorly bedded to massive, soft, very fine-grained, maroon sandstone and sandy siltstone, although most sections have a few thin beds of greenish gray siltstone and one or two beds of red, pink, or rarely white medium-grained sandstone. The sand grains are characteristically well rounded. The coarser-grained sandstones are most common in the member in the southern and southeastern parts of the Black Hills, particularly east of Hot Springs. The member is softest, least sandy, and least conspicuous in the northwestern part of the Black Hills. It is differentiated from the red Spearfish formation by being a somewhat lighter red, by weathering to a lighter pinkish red, by lacking gypsum in some sections, by being more poorly bedded, and by its small, well rounded sand grains. A disconformable relationship with the overlying Redwater shale member is indicated by an abrupt change from unfossiliferous red beds to highly fossiliferous sandstone and shale and possibly by the marked local variations in thickness of the Lak member.

[43] Love *et al.*, *op. cit.* (1945).

Correlation.—The Lak member is correlated (Table I) on the basis of stratigraphic position with the redbeds at the top of the "Lower Sundance" in central Wyoming, with the Preuss sandstone of westernmost Wyoming and eastern Idaho and with at least part of the Entrada sandstone of eastern Utah.[44] It is much younger than the upper redbed member of the Gypsum Spring formation of north-central Wyoming and southern Montana with which it has been confused. It has not been identified in the northern part of the Big Horn Basin of northern Wyoming or anywhere in Montana. For these latter areas, four possibilities may be considered. First, they underwent erosion during Lak time; second, they received normal, dark marine clayey sediments, while red sediments were accumulating along the margins of the seaway in the Black Hills area, in central Wyoming, and in eastern Idaho and Utah; third, they received a thin veneer of red sediments during Lak time that was removed by erosion before deposition of the Swift formation; fourth, they received continental sediments that were not reddish, or were bleached subsequently to yellows and grays. None of these possibilities can be ruled out on the basis of present information, but the first possibility seems most probable to the writer as far as Montana is concerned because of the extensive erosion that occurred between Rierdon and Swift times, especially in the areas of the Sweetgrass arch and the Little Belt Mountains. The evidence for erosion in the Sweetgrass arch area has been discussed fully by Cobban.[45] The evidence for erosion in the area of the Little Belt Mountains has been mentioned by the writer.[46] The evidence consists partly of the superposition of the Swift formation on any part of the Rierdon and Sawtooth formations, or on upper Paleozoic rocks, and partly of the coarse, chert and quartzite conglomerate at the base of the Swift formation. The distribution of the conglomerate shows that it was derived from areas along the site of the Little Belt Mountains. The existence of hills or island masses in central Montana even earlier is indicated by the considerable amount of silty and sandy sediment in the Rierdon formation of the Big Snowy Mountains in contrast to the absence of such sediment in that formation in most parts of Montana. Similarly, extensive erosion between the Rierdon and Swift formations has been recognized in the southwestern part of Montana, but details can not be given here. This contrasts with conditions in the Pryor Mountains of south-central Montana and the Big Horn Basin of north-central Wyoming, where the only physical evidence of an unconformity is an abrupt change from non-glauconitic shale or fine-grained sandstone or sandy limestone to highly glauconitic coarse-grained, impure sandstone and shale. Evidently between Rierdon and Swift times Montana was much more uplifted and

[44] Bartram, *op. cit.* (1940), pp. 117, 118; "Triassic-Jurassic Red Beds of the Rocky Mountain Region," *Jour. Geology,* Vol. 38 (1930), pp. 335–43, 667–79.

[45] W. A. Cobban, "Marine Jurassic Formations of Sweetgrass Arch, Montana," *Bull. Amer. Assoc. Petrol. Geol.,* Vol. 29 (1945), pp. 1262, 1285–90.

[46] Ralph W. Imlay, "Occurrence of Middle Jurassic Rocks in Western Interior of United States," *Bull. Amer. Assoc. Petrol. Geol.,* Vol. 29 (1945), pp. 1026, 1027.

eroded along both northwesterly and easterly trends than were areas to the south. This suggests that uplift in Montana, particularly along an easterly trend, at the end of Rierdon time rather suddenly cut off the southern part of the Jurassic seaway, which then became the site of widespread deposition of non-fossiliferous redbeds, including the Entrada sandstone, Preuss sandstone, and the Lak member of the Sundance formation.

Some evidence possibly contrary to the thesis that the area of Montana underwent erosion during Lak time is furnished by the presence of about 35 feet of dark reddish brown, pinkish brown, and greenish gray shale at the depths of 5,155 to 5,190 feet in the California Company's Kamp No. 1 in Williams County, northwestern North Dakota.[47] This varicolored shale appears to have the same stratigraphic position as the Lak member of the Sundance formation in the Black Hills. Of course, an uplift in central Montana at the end of Rierdon time may not have had much influence as far east as North Dakota, other than cutting off marine waters. Also there may have been differential uplift during Lak time, resulting in irregularly shaped basins, as evidently occurred during deposition of the Entrada sandstone.[48]

Origin.—The lack of marine fossils in the Lak member might be considered as evidence of its continental origin. However, its gradational relationship with marine Hulett sandstone member shows it must be basally of marine or brackish-water origin. Its homogeneous character and lack of cross-bedding suggest that it was deposited in fairly quiet waters. Determination of its probable environment of deposition should take into account all data concerning equivalent redbeds in the Western Interior region[49] which appear to be partly water-laid and partly wind-laid and mainly, or entirely non-marine.

REDWATER SHALE MEMBER

Definition.—The Redwater shale member of the Sundance formation consists of 80 to 190 feet or more of greenish gray to gray, soft, fissile shale that includes some soft, glauconitic sandstone in the lower 20 to 30 feet and some thin beds of coquinoid or oölitic limestone in the upper half. The contact with the overlying Morrison formation is perfectly gradational within an interval of 10 to 15 feet and must generally be chosen arbitrarily. The type section is designated as the bluff ½ mile north of Redwater Creek, near the mouth of Crow Creek, 9 miles northwest of Spearfish, in the S. ½ of Sec. 2, T. 7 N., R. 1 E., Butte County, South Dakota. At this locality the lower 18 feet of the member consists of alternating beds of gray shale and soft yellow sandstone. The upper 118 feet consists

[47] Virginia H. Kline, *op. cit.*, p. 372.

[48] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936), p. 46 and Fig. 12 on p. 49.

[49] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., *op. cit.*, pp. 7, 46.
G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 98, 99.

mainly of soft, dark gray shale, but contains lenses of sandy limestone at several levels and many limestone concretions in the upper half. It is overlain by 5 to 10 feet of soft, yellow sandstone and that by gray shale containing small calcareous pellets typical of the Morrison formation.

Stratigraphic and lithologic features.—The Redwater shale member (Figs. 2 and 3) averages 100 to 150 feet in thickness, seems to be a little thicker along the western than the eastern side of the Black Hills, and is less than half as thick as similar equivalent shaly beds recorded from the Cedar Creek anticline in Fallon County, easternmost Montana, or from the Williston Basin in North Dakota.[50] The bulk of the member consists of greenish gray shale that is locally silty basally, and is characterized by selenite and many belemnites. The limestone beds in the upper part of the member are mainly a coquina of *Eumicrotis* shells. Limestone concretions are fairly common in the middle and upper parts of the member, and some are very fossiliferous. The sandstone beds in the lower 20 to 30 feet are generally soft, yellow, and highly glauconitic. In some sections these sandstone beds alternate with some maroon siltstone and sandstone nearly identical with the redbeds in the underlying Lak member. The basal contact is abrupt and marked by highly glauconitic sandstone resting on non-glauconitic redbeds. At many localities the contact with the Morrison formation may conveniently be chosen at the top of a bed of glauconitic sandstone or sandy limestone, but in some localities there seems to be a very gradual transition from fossiliferous, marine, gray shale to silty, non-marine, gray, green, or maroon shale. In the southeastern part of the Black Hills the upper contact of the Sundance formation is easy to choose, because of the presence of the overlying massive Unkpapa sandstone.

Typical sections of the Redwater shale member are described at the end of this paper.

Correlation.—The Redwater shale member of the Sundance formation correlates faunally with the Curtis formation of Utah, the Stump sandstone of eastern Idaho and westernmost Wyoming, the Swift formation of Montana, and the "Upper Sundance" formation in central Wyoming (Table I). The basal beds of these formations have not furnished diagnostic ammonites except in the Little Rocky Mountains and the Bearpaw Mountains of central Montana. At these localities concretionary beds from 20 to 30 feet above the base of the Swift formation have furnished numerous specimens of *Quenstedtoceras* (*Bourkelamberticeras*) *collieri* Reeside associated with a few specimens of *Pavloviceras* and rare specimens of *Scarburgiceras*, *Maltoniceras*, and a perisphinctid probably belonging to *Prososphinctes*. The writer considers that these fossils represent the boundary of the *lamberti* and *mariae* zones of Europe, because of the abundance of *Bourkelamberticeras*, which is typical of the *lamberti* zone but ranges into the *mariae* zone, and

[50] W. M. Laird, "Selected Deep Well Records," *North Dakota Geol. Survey Bull. 12* (1941), pp. 11, 12.

Virginia H. Kline, *op. cit.*, pp. 371, 372, 376.

because *Pavloviceras* and *Scarburgiceras* are characteristic of the *mariae* zone and are not known below the upper part of the *lamberti* zone.

Faunal correlation of the Redwater shale member of the Sundance formation with the Stump, Curtis, and Swift formations is based on the widespread distribution of *Cardioceras*, especially the subgenus *Scarburgiceras*, and associated species of *Goliathiceras* and *Pachycardioceras* near the top of the lower third or half of these formations. *Cardioceras* (*Scarburgiceras*) *cordiforme* (Meek and Hayden) is the most common species, and the beds which it characterizes are considered to represent the *mariae* zone of northwest Europe. Now *Scarburgiceras* ranges from the upper part of the *lamberti* zone into the base of the *cordatum* zone. Most of the other subgenera of *Cardioceras*, such as *Scoticardioceras*, *Subvertebriceras*, and *Cardioceras*, associated with *Scarburgiceras* in the Western Interior, are known to range in Europe from the *mariae* to the *cordatum* or *plicatilis* zones, although *Maltoniceras*, *Vertebriceras*, and *Sagitticeras* have not been found below the *cordatum* zone, according to any records that the writer has examined. *Goliathiceras* is recorded most frequently from the *cordatum* zone, although the subgenus *Pachycardioceras* occurs as low as the *mariae* zone. Judging from these European ranges the beds with *Cardioceras cordiforme* would appear to represent the upper part of the *mariae* zone and the basal part of the *cordatum* zone. However, in the Little Rocky Mountains and the Bearpaw Mountains of north-central Montana, *Cardioceras* (*Vertebriceras*) *whiteavesi* Reeside, and *C.* (*Maltoniceras*) *sundancense* Reeside occur just a few feet above the beds containing *Quenstedtoceras* (*Bourkelamberticeras*) *collieri* Reeside, which can scarcely be higher than the basal part of the *mariae* zone. The fossils occur in well exposed shales that lack any features suggestive of a disconformity. It would appear, therefore, that the range of *C. cordiforme* represents most of the *mariae* zone, and that some of the subgenera of *Cardioceras* have slightly different ranges in the Western Interior from those recorded in Europe. One thing suggesting that *C. cordiforme* does not range above the *mariae* zone is the occurrence of a grossouvrid greatly resembling *Grossouvria* (*Poculisphinctes*) *trina* (Buckman)[51] in the same bed with *C. cordiforme* about 55 feet above the base of the Redwater shale, 1 mile north of Redwater Creek, opposite the mouth of Crow Creek, Butte County, South Dakota. This subgenus has been recorded most commonly in Europe from the *athleta* and *lamberti* zones and rarely from the *mariae* zone.

The upper half of the Redwater shale member has not furnished ammonites. Nor have higher zones of the Oxfordian been identified in the Western Interior. Perhaps the *plicatilis* zone is represented by some fragmentary cardioceratids, apparently belonging to *Cardioceras* and *Maltoniceras*, from the upper part of the "Upper Sundance" in the Wind River Basin. In most places the highest beds of the marine Jurassic, which stratigraphically should represent the upper Oxfordian are composed mainly of sandy beds containing such fossils as *Eumicrotis*, *Camptonectes*, *Ostrea*, and *Gryphaea*. The boundary between the Sundance formation,

[51] S. S. Buckman, "Yorkshire Type Ammonites," Vol. IV (1922), Pl. 332.

or its equivalents, and the overlying Morrison formation need not be of exactly the same age throughout the Western Interior, but is considered to correspond roughly with the Oxfordian-Kimmeridgian boundary, because that time marked the beginning of extensive uplift in the southern United States and in Mexico.[52] However, the complete absence of *Aucella* in the marine Jurassic of the Western Interior region of the United States suggests that the Morrison formation may include beds of upper Oxfordian age. Striate aucellas, such as *Aucella bronni* Rouillier, are fairly common in the Pacific northwest, in Alaska, and in the Arctic regions, in beds of Kimmeridgian age,[53] but in Russia have been recorded rarely in the upper Oxfordian zone of *Amoeboceras alternans*[54] which corresponds basally with the zone of *Decipia decipiens*, according to Arkell.[55]

The Redwater shale member has furnished many fossils, including most of those described by Whitfield,[56] Whitfield and Hovey,[57] and Reeside.[58]

Data concerning the exact stratigraphic position of most of these fossils are lacking. The following collections were made by Wm. Saalfrank and the writer.

Two miles east-southeast of Minnekahta, a large concretion 59 feet above the base of the Redwater shale member has furnished the following (U.S.G.S. Mes. loc. 19571).

Cardioceras (*Cardioceras*) *distans* var. *depressum* Reeside
C. (*Cardioceras*) *stantoni* var. *obesum* Reeside
C. (*Cardioceras*) n. sp. aff. *C. hyatti* Reeside
C. (*Cardioceras*) n. sp.
C. (*Sagitticeras*) cf. *C. latum* Reeside
Ostrea sp.
Grammatodon inornatum (Meek and Hayden)
Pleuromya newtoni Whitfield
Tellinomya? protensa Hall
Proeconia n. sp.
Protocardia shumardi Meek and Hayden
Eumicrotis curta (Hall)
Tancredia transversa Whitfield and Hovey

[52] Ralph W. Imlay, "Jurassic Formations of Gulf Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27 (1943), pp. 1415, 1474, 1526.

[53] George C. Martin, "The Mesozoic Stratigraphy of Alaska," *U. S. Geol. Survey Bull. 776* (1926), p. 282.

[54] A. P. Pavlov, "Enchaînement des Aucelles et Aucellines du Crétacé Russe," *Nouveaux Mémoires de la Société Imperiale des Naturalistes de Moscou*, Vol. XVII (1907), pp. 11, 73, 74.
D. Sokolov, "Aucelle von Timau und von Spitzbergen," *Mémoires du Comité Géologique*, nou. série, livr. 36 (1908), p. 2.
L. F. Spath, "The Upper Jurassic Invertebrate Faunas of Cape Leslie, Milne Land I. Oxfordian and Lower Kimmeridgian," *Meddelelser om Grønland*, Vol. 99, No. 2 (1935), p. 73.

[55] W. J. Arkell, "Standard of the European Jurassic," *Bull. Geol. Soc. America*, Vol. 57 (1946), p. 24.

[56] R. P. Whitfield, "Paleontology of the Black Hills of Dakota," in Henry Newton and W. P. Jenney, "Report on the Geology and Resources of the Black Hills of Dakota," *U. S. Geog. Geol. Survey Rocky Mountain Region* (1880), pp. 344–82, pls. 3–6.

[57] R. P. Whitfield and E. O. Hovey, "Remarks on and Descriptions of Jurassic Fossils of the Black Hills," *Bull. Amer. Mus. Nat. Hist.*, Vol. XXII, Art. XXIII (1906), pp. 389–402.

[58] John B. Reeside, Jr., "Some American Jurassic Ammonites of the Genera *Quenstedticeras*, *Cardioceras*, and *Amoeboceras*, family Cardioceratidae," *U. S. Geol. Survey Prof. Paper 118* (1919).

At the same locality but across a small ravine a concretion was found lying loose on the surface about 34 feet above the base of the Redwater shale member and 10 feet below the top of a small hill. It contained the following (U.S.G.S. Mes. loc. 19568).

Cardioceras (*Scoticardioceras*) aff. *C. alaskense* Reeside
Pachyteuthis sp.
Astarte dacotensis Whitfield and Hovey
Eumicrotis curta (Hall)

Directly below on the same slope a concretion about 26 feet above the base of the Redwater shale member furnished the following (U.S.G.S. Mes. loc. 19567).

Cardioceras (*Cardioceras*) *auroraense* Reeside
C. (*Cardioceras*) *stantoni* Reeside
Pachyteuthis "densus" (Meek and Hayden)
Astarte dacotensis Whitfield and Hovey
Eumicrotis curta (Hall)
Camptonectes sp.
Grammatodon inornatum (Meek and Hayden)

On the north side of Bush Canyon 2½ miles north of Hulett, Wyoming, a collection made 28 feet above the base of the Redwater shale member contained (U.S.G.S. Mes. loc. 19569).

Cardioceras (*Scarburgiceras*) cf. *C. cordiforme* (Meek and Hayden)
Tancredia transversa Whitfield and Hovey

One of the most significant collections was obtained 73 feet above the base of the member on the north side of Redwater Creek opposite the mouth of Crow Creek, about 9 miles northwest of Spearfish, South Dakota (U.S.G.S. Mes. loc. 19570). This locality furnished the following.

Cardioceras (*Scarburgiceras*) *cordiforme* (Meek and Hayden)
C. (*Scarburgiceras*) *wyomingense* Reeside
Grossouvria (*Poculisphinctes*) n. sp. aff. *P. trina* (Buckman)
Pachyteuthis sp.
Pholadomya obscura Whitfield and Hovey
Pleuromya newtoni Whitfield
Tancredia? sp.
Pinna jurassica Whitfield and Hovey
Volsella formosa (Meek and Hayden)
Corbicellopsis? n. sp.

Since publication of Reeside's paper on the North American forms of Cardioceratidae, the European representatives have been studied rather intensely, have been much subdivided, the taxonomy proposed by Buckman in his *Type Ammonites* has been interpreted, and the ranges of the various genera and subgenera have become better known. As it may be useful, from the viewpoint of regional correlation, to assign the American species to the subgenera and genera now generally recognized in Europe, the writer has prepared Table III.

Origin.—A rather sudden flooding of land masses at the beginning of deposition of the Redwater shale member is indicated by the superposition of normal marine sandstone and shale directly on non-fossiliferous redbeds. Some thin red shale and siltstone beds in the basal part of the Redwater shale member may reasonably be interpreted as reworked from the underlying Lak member.

The waters were probably not extremely shallow, as the sandstones are highly glauconitic and do not show ripple marks. However, subsidence was much slower than in easternmost Montana and western North Dakota, where similar equivalent beds are more than twice as thick. Sources of the clastic sediments were evidently mostly from the west, as the equivalent beds in Wyoming and Montana are much sandier, especially in their upper part.

TABLE III

AMERICAN SPECIES OF CARDIOCERATIDAE

Names Used by J. B. Reeside, Jr.	*Proposed Assignment*		*Zonal Range of Subgenera*
	Genus	*Subgenus*	
Cardioceras auroraense Reeside *distans* (Whitfield) *distans* var. *depressum* Reeside *stantoni* Reeside *stantoni* var. *obesum* Reeside *hyatti* Reeside *schucherti* Reeside		*Cardioceras*	*mariae* to *plicatilis*
Cardioceras alaskense Reeside *whitfieldi* Reeside *stillwelli* Reeside ? sp. Reeside		*Scoticardioceras*	*mariae* to *plicatilis*
Cardioceras martini Reeside *cordiforme* (Meek and Hayden) *americanum* Reeside *wyomingense* Reeside	*Cardioceras*	*Scarburgiceras*	upper *lamberti* to lower *cordatum*
Cardioceras sundancense Reeside *prionodes* Crickmay *plattense* Reeside *lillooetense* Reeside		*Maltoniceras*	*cordatum* to *plicatilis*
Cardioceras canadense Reeside		*Subvertebriceras*	*upper mariae* to *plicatilis*
Cardioceras whiteavesi Reeside		*Vertebriceras*	*cordatum* to *plicatilis*
Cardioceras hayesi Reeside *obtusum* Reeside ? *latum* Reeside		*Sagitticeras*	*cordatum* to *plicatilis*
Cardioceras crassum Reeside *russelli* Reeside ? *incertum* Reeside ? *albaniense* Reeside *bellefourchense* Reeside	*Goliathiceras*	*Pachycardioceras*	*mariae* to *plicatilis*
Quenstedticeras? hoveyi Reeside ? *subtumidum* (Whitfield and Hovey) ? *suspectum* Reeside		*Goliathiceras*	*cordatum* to *plicatilis*
Quenstedticeras collieri Reeside	*Quenstedtoceras*	*Bourkelamberticeras*	*lamberti* to *mariae*
Cardioceras spiniferum Reeside	*Amoeboceras*	*Prionodoceras*	*cautisnigrae* to *cymodoce*(?)
Amoeboceras dubium Hyatt		*Amoebites*	lower *Kimmeridgian*

GEOLOGIC HISTORY

Jurassic sedimentation in the Black Hills area may have begun in the Lower Jurassic with the accumulation of a slight thickness of wind-blown sand probably representing the eastern margin of the Nugget sandstone.

Marine sedimentation in the Black Hills area began in the early Middle Jurassic, when shallow marine waters spread eastward rapidly from the deepest

part of the Jurassic trough in eastern Idaho and central Utah and deposited as much as 250 feet of gypsiferous redbeds, dolomite, and limestone, called the Gypsum Spring formation, over wide areas in Wyoming, Montana, and parts of the Dakotas. The first marine spreading occurred during the upper Bajocian, according to present information, filled in the gentle irregularities of an old erosion surface, deposited thick masses of massive white gypsum and some associated red or maroon siltstone and claystone that locally attain 125 feet in thickness, and are similar in appearance to the underlying Lower Triassic redbeds from which they probably were derived. Deepening and spreading of the sea continued during the lower Bathonian until normal marine waters reached as far east as the areas of the Wind River and Big Horn basins of Wyoming and the Pryor Mountains of southern Montana, interfingering there with redbeds, dolomite, and dolomitic limestone. Farther north, marine waters apparently reached as far east as northwestern North Dakota. Retreat of the sea occurred during the upper Bathonian, resulting in some erosion in the Black Hills and the Wind River Basin areas but depositing from 50 to 100 feet of redbeds and gypsum in the Big Horn Basin and in southernmost Montana and from 20 to 100 feet of marine silty to sandy, or even pebbly beds, in central, northern, and western Montana. Uplift from the east was probably the immediate cause of marine withdrawal, as indicated by the eastward coarsening of the marine sandy beds in northern Montana. Thus this advance and retreat of the sea during the Middle Jurassic resulted in a normal marine facies lying between redbed facies, but all passing westward in Idaho and western Montana into dark marine siltstone, shale, and shaly limestone.

The next eastward advance of the sea in the Black Hills area occurred during the lower Callovian, reworked some surficial sands into the Canyon Springs sandstone member and then deposited the Stockade Beaver shale member consisting of 50 to 85 feet of normal marine gray shale, minor amounts of siltstone, and sandstone, and locally a basal conglomerate. The advance was probably rapid, as the underlying redbeds do not appear to have been reworked appreciably and the basal part of the shale correlates faunally with the basal gray shales of the Rierdon formation of Montana and the Sundance formation of Wyoming.

The Stockade Beaver shale member was overlain transitionally by 25 to 120 feet of marine, mostly gray to yellow sandstone, and some sandy shale, called the Hulett sandstone member of the Sundance formation. That in turn was overlain transitionally by 25 to 100 feet of non-fossiliferous red sandstone and siltstone called the Lak member. This sequence is similar to that in the "Lower Sundance" of the Wind River Basin of central Wyoming, and possibly to that in the Williston Basin of North Dakota, but unlike that in Montana or northernmost Wyoming, where redbeds corresponding with the Entrada sandstone are lacking. Regional relationships show that the sandy material in the Stockade Beaver shale member and the Hulett sandstone member came from the east or southeast. The source of sediments in the Lak member is unknown but was presumably from the east or south. It seems probable that uplift in central Montana, particularly along an

easterly trend, during middle Callovian time rather abruptly isolated the southern end of the Jurassic seaway from direct marine connections on the north. Continued sinking of the southern end of the seaway during middle Callovian time resulted in the deposition of non-marine redbeds extending from the Black Hills area southwestward across southern Wyoming to Utah and Idaho. Thus the Entrada sandstone, Preuss sandstone, and Lak member of the Sundance formation were formed in an irregular, elongate basin south of the low broad arch in central Montana. Redbed deposition was finally terminated by uplift in the Black Hills area and farther west during the middle or upper Callovian. The erosion that followed was apparently slight, but may explain some of the irregularities in thickness of the Lak member.

The last Jurassic marine invasion of the Black Hills area occurred at the end of the Callovian, or at the beginning of the Oxfordian. This resulted in the deposition of 80 to 190 feet of greenish gray shale that is called the Redwater shale member of the Sundance formation. It includes some glauconitic sandstone basally, many beds of coquinoid limestone in the upper part, and generally some sandy beds at the top that are transitional into the overlying non-marine Jurassic. Marine flooding was fairly rapid, although locally there appears to have been considerable reworking of the underlying redbeds. The basal sands were most likely of local derivation, but the higher sands were probably derived from the west because regional relationships show that the Redwater shale member passes westward into sandier sediments whose source was farther west in Idaho and Nevada. Evidently uplift of land areas in these states became more pronounced during the Oxfordian, as sandy sediment extended farther and farther east, eventually reaching South Dakota near the end of deposition of the Redwater shale member. The duration of marine sedimentation is not known, but is assumed to have continued until nearly the end of Oxfordian time, as suggested by the complete lack of the pelecypod *Aucella* in the Western Interior region of the United States, and by the probability that widespread uplift corresponded with a major uplift in the Gulf of Mexico region. Gradual withdrawal of marine waters is suggested by the transitional boundary of the marine Redwater shale member with the overlying non-marine Morrison formation. Most likely marine waters persisted for a short time in some parts of the Western Interior region, while continental sedimentation was taking place in other parts.

LOCAL SECTIONS

GYPSUM SPRING AND SUNDANCE FORMATIONS ONE MILE NORTH OF REDWATER CREEK IN S. ½ OF SEC. 2, T. 7 N., R. 1 E., ABOUT 9 MILES NORTHWEST OF SPEARFISH, SOUTH DAKOTA

Feet

Morrison formation

Sundance formation

Redwater shale member

22. Shale, silty near base, dark gray; contains many pieces of selenite and abundant belemnites; lenses of sandy limestone present at several levels; many fossiliferous limestone concretions in upper half; overlain by 5 to 10 feet of soft yellow sandstone and that, in turn, by dark gray shale containing small calcareous pellets assigned

	Feet
to the Morrison formation. U.S.G.S. Mes. loc. 19570, 55 feet above base in lens of sandy limestone, contains *Cardioceras* (*Scarburgiceras*) *cordiforme* (Meek and Hayden), *C.* (*S.*) *wyomingense* Reeside, *Grossouvria* (*Poculisphinctes*) cf. *G. trina* (Buckman), and other fossils listed under "correlation" of Redwater shale member	118
21. Sandstone, soft, medium-yellow, shaly to thick-bedded	6
20. Shale and sandy shale, soft, gray	10
19. Sandstone, soft, yellow	1
18. Shale, soft, gray	1
Total thickness of Redwater shale member	136
Lak member	
17. Sandstone, fine-grained and siltstone, light red, weathers pinkish; contains 2 feet of soft white sandstone about 24 feet above base	50
Hulett sandstone member	
16. Shale, greenish gray	6
15. Sandstone, thin-bedded to shaly, glauconitic, poorly exposed	19
14. Sandstone, medium-bedded, soft, salmon-pink to yellowish	5
13. Shale, sandy, soft, yellowish gray	5
12. Sandstone, very massive, forming sheer cliff; ripple-marked, light yellow to pinkish yellow; weathers buff	40
11. Sandstone, thin-bedded to shaly; some thick beds in middle; yellowish gray to greenish gray, glauconitic	37
10. Sandstone, massive, light yellow	9
Total thickness of Hulett sandstone member	121
Stockade Beaver shale member	
9. Shale, dark gray, soft, calcareous	26
8. Sandstone, white, massive, fairly soft	5
7. Shale, medium to dark gray, soft, partly silty, calcareous, some gray, chert-like pebbles at base	21
6. Conglomerate, fine, pieces of red siltstone and light-colored quartz stained green on surface; present locally	½
Total thickness of Stockade Beaver shale member	52½
Total thickness of Sundance formation	359+
Gypsum Spring formation	
5. Shale, red, soft	14
4. Sandstone, white, massive, fairly soft	2
3. Shale, in part sandy, greenish gray	4
2. Siltstone, red, fairly soft	6
1. Dolomite, brecciated, fairly hard, light gray; contains angular pieces of dark gray, chert-like metamorphic rock. Contact with underlying redbeds of Spearfish formation is slightly irregular and upper layer of redbeds appears to have been reworked.	3
Total thickness of Gypsum Spring formation	29

SUNDANCE FORMATION, 6 MILES SOUTH OF RAPID CREEK, OR 5 MILES SOUTH OF SOUTHERN LIMIT OF RAPID CITY, AT ROAD CUT ON U. S. HIGHWAY 16, SE. ¼ SEC. 34, T. 1 N., R. 7 E., PENNINGTON COUNTY, SOUTH DAKOTA

	Feet
Sundance formation (part)	
Redwater shale member (part)	
23. Shale, greenish gray, soft; weathers yellowish gray; some selenite present; about 4 feet above base occurs 1 foot of fine-grained, gray, glauconitic, thin-bedded sandstone; next overlying 8 feet are silty; some belemnites present; upper contact not exposed	22
22. Sandstone, yellow, fine-grained, very soft, glauconitic	13
21. Shale, greenish gray, soft	8
20. Sandstone, salmon-red, fine-grained, medium- to thin-bedded	7

	Feet
19. Shale, greenish gray, soft	5
18. Sandstone, mostly pink, some pinkish yellow, fine-grained, thin-bedded to shaly; weathers pinkish	2½
17. Shale, dark gray, soft, many selenite crystals	10
16. Sandstone, yellow, fine-grained; upper surface irregular and stained red; rests sharply on irregular surface of underlying redbeds	2
Total exposed thickness of Redwater shale member (205 feet thick in Rapid City Airport well)	69½
Lak member	
15. Sandstone, maroon, soft, very fine-grained; some siltstone and shale at top	12
14. Siltstone, maroon, soft	5
13. Sandstone, maroon, soft, very fine-grained	5
12. Siltstone, maroon, soft	3
11. Sandstone, maroon, soft, very fine-grained	2
10. Siltstone, maroon, soft	33
9. Sandstone, maroon, soft, very-fine-grained	4
8. Siltstone, maroon, soft	12
Total thickness of Lak member	76
Hulett sandstone member	
7. Shale, greenish gray, some pink; some thin layers of red siltstone	8
6. Sandstone, pink to light yellow, mostly thick-bedded, some thin-bedded, ripple-marked, fine-grained, fairly hard, glauconitic; forms low cliff	15
Total thickness of Hulett sandstone member	23
Stockade Beaver shale member	
5. Shale, dark gray; some thin beds of pink sandstone in upper part; poorly exposed; grades into overlying unit	30
4. Sandstone, pink to yellowish gray, fine-grained, hard	3
3. Siltstone, shale, and thin layers of sandstone, greenish gray and maroon, soft; some specimens of *Tancredia*	3
2. Shale, dark gray, soft	27
1. Sandstone; lower part white, medium-grained, very porous; upper part dense and yellow; weathers buff; possibly equivalent to basal sandstone of Sundance group in southern part of Black Hills	1½
Total thickness of Stockade Beaver shale member	64½
Total exposed thickness of the Sundance formation	233
Spearfish formation	

SUNDANCE FORMATION ON BEAVER CREEK 2 MILES NORTHWEST OF BUFFALO GAP AND 9 MILES NORTHEAST OF HOT SPRINGS IN SEC. 13, T. 6 S., R. 6 E., CUSTER COUNTY, SOUTH DAKOTA

	Feet
Unkpapa sandstone	
Sundance formation	
Redwater shale member	
9. Shale, greenish gray, soft; lower 15 feet fairly sandy; upper 25 feet contains many limestone beds from 2 inches to 2 feet thick, consisting mostly of *Eumicrotis* shells; belemnites are fairly common in the shales; rather poorly exposed except near contacts; overlain by the massive Unkpapa sandstone	100±
Lak member	
8. Siltstones, sandy, maroon, interbedded with soft maroon sandstone; at base are about 5 feet of yellowish to pinkish sandstones	65

	Feet
Hulett sandstone member	
7. Shale, greenish gray, some maroon; weathers grayish buff; grades into overlying redbeds	15
6. Sandstone, slabby, ripple-marked glauconitic, yellowish to pinkish gray; weathers buff; contains partings of gray shale; upper foot has furnished *Quenstedtia arcuata* (Meek and Hayden), *Q. aequilateralis* (Meek and Hayden), *Q.* aff. *Q. postica* (Whitfield) at U.S.G.S. Mes. loc. 19566	22
Stockade Beaver shale member	
5. Shale, dark gray; some thin layers of yellowish gray sandstone at top; contains *Eumicrotis curta* (Hall) at U.S.G.S. Mes. loc. 19557	6
Canyon Springs sandstone member	
4. Shale, mostly maroon, some gray	13
3. Sandstone, massive, soft, cross-bedded, salmon-colored	12
2. Shale, maroon and gray, weathering buff; partly sandy, some thin beds of yellowish gray sandstone in upper 5 feet. *Trigonia conradi* Meek and Hayden obtained from upper foot at U.S.G.S. Mes. loc. 19565	10
1. Sandstone, gray, hard; rests on red shale of Spearfish formation	5
Total thickness of Sundance formation	248+
Spearfish formation	

SUNDANCE FORMATION, 2 MILES EAST-SOUTHEAST OF MINNEKAHTA IN S. ½ SEC. 21, T. 7 S., R. 4 E., FALL RIVER COUNTY, SOUTH DAKOTA

	Feet
Morrison formation	
Sundance formation (part)	
Redwater shale member	
14. Limestone, gray, overlain by about 150 feet of maroon and gray sandstone and shale of the Morrison formation	2
13. Sandstone, dark-yellow, weathering lighter yellow, soft, medium-bedded	5
12. Shale, greenish gray to gray, soft, fissile, weathering dark yellow; upper half contains a few thin limestone beds composed mainly of *Eumicrotis* shells; limestone concretions occur throughout lower half but are most common near middle of unit. Collections containing *Cardioceras*, among other fossils, were obtained at U.S.G.S. Mes. loc. 19571 about 35 feet above base; U.S.G.S. Mes. loc. 19568 about 10 feet above base; U.S.G.S. Mes. loc. 19567 about 2 feet above base. The fossils from these localities are listed under "correlation" of the Redwater shale member	73
11. Sandstone, soft, dark yellow; beds from 2 to 6 inches thick; some partings of sandy shale	2
10. Sandstone, soft, yellowish gray, alternating with maroon siltstone and sandstone and greenish gray shale; weathers buff; contact with underlying redbeds abrupt	19
Total thickness of Redwater shale member	104
Lak member	
9. Siltstone and sandstone, maroon	85
8. Siltstone, maroon, alternating with thin layers of pink and buff sandstone	15
Total thickness of Lak member	100
Hulett sandstone member	
7. Shale, soft, fissile, dark gray	15
6. Shale, soft, fissile, dark gray, partly sandy; upper half contains some thin beds of maroon siltstone and several 1- to 4-inch beds of soft, yellowish white sandstone; *Pentacrinus asteriscus* Meek and Hayden present	13
5. Sandstone, massive, rather soft, ripple-marked, yellowish gray; weathers grayish; glauconitic	11
4. Sandstone and shale. Alternating beds ¼ to 2 inches thick of pink, white, or buff sandstone and dark gray shale; becomes thicker-bedded upward; sandstones are ripple-marked, glauconitic	8
Total thickness of Hulett sandstone member	47

	Feet
Stockade Beaver shale member (part)	
3. Shale, very soft, fissile, dark gray; U.S.G.S. Mes. loc. 19555 yields ***Lingula brevirostris*** Meek and Hayden, ***Eumicrotis curta*** (Hall), ***Pleuromya subelliptica*** (Meek and Hayden), *Tancredia* cf. *T. warrenana* Whitfield, ***Corbicellopsis? inornata*** (Meek and Hayden), *Pachyteuthis* sp.	48
2. Shale, dark gray, weathering gray; contains thin beds of nodular limestone that have furnished *Arcticoceras henryi* (Meek and Hayden) and *Arcticoceras* n. sp. at U.S.G.S. Mes. loc. 19556	6
1. Shale, dark gray, soft, fissile; some very thin partings of buff siltstone; weathers grayish buff; base concealed	10+
Total exposed thickness of Stockade Beaver shale member	64+
Total exposed thickness of Sundance formation	315+

The basal beds of the Sundance formation are not exposed in the above described section, but about 3 miles east of Minnekahta on the south side of the main highway the redbeds at the top of the Spearfish formation are overlain along a sharp contact by at least 15 feet of white to pinkish white sandstone belonging to the lower part of the Canyon Springs sandstone member.

GYPSUM SPRING AND SUNDANCE FORMATIONS ON NORTH SIDE OF BUSH CANYON 2½ MILES NORTH OF HULETT IN SECS. 25 AND 36, T. 55 N., R. 65 W., CROOK COUNTY, WYOMING

	Feet
Morrison formation	
Sundance formation	
Redwater shale member	
18. Shale, medium-gray, soft, poorly exposed; ledges of fossiliferous limestone at 20 feet and 45 feet above base, overlain by about 30 feet of soft yellow sandstone that is possibly correlative with the Unkpapa sandstone	60
17. Limestone, sandy, fossiliferous	3
16. Shale, dark gray	36
15. Shale, gray, mostly covered; some layers of limestone and concretions of limestone in lower part; belemnites abundant	36
14. Sandstone, calcareous; at top, U.S.G.S. Mes. loc. 19569 has furnished *Cardioceras* (*Scarburgiceras*) cf. *C. cordiforme* (Meek and Hayden) and *Tancredia transversa* Whitfield and Hovey	5
13. Shale, gray; many belemnites; mostly covered	18
12. Sandstone, light yellow, soft	5
Total thickness of Redwater shale member	163
Lak member	
11. Sandstone and siltstone, red, poorly exposed	42
Hulett sandstone member	
10. Sandstone, thin-bedded to shaly, interbedded with sandy shale, poorly exposed, glauconitic	13
9. Sandstone, thick-bedded, ripple-marked, fine-grained, light-yellow to pink; forms cliffs about 40 feet high	57
8. Shale, gray, sandy, interbedded with beds of fine-grained, ripple-marked, yellow sandstone from 2 to 8 inches thick, glauconitic	12
Total thickness of Hulett sandstone member	82
Stockade Beaver shale member	
7. Shale, medium gray, soft; contains much selenite; grades into overlying unit	50
6. Sandstone, light yellow, soft	14
5. Shale, medium gray, soft, partly silty	12
Total thickness of Stockade Beaver shale member	76
Total thickness of Sundance formation	363

	Feet
Gypsum Spring formation	
4. Limestone, shaly, medium gray, weathering light gray; in upper part, U.S.G.S. Mes. loc. 19564 has furnished *Lingula brevirostris* Meek and Hayden, *Eumicrotis curta* (Hall), *E. orbiculata* (Whitfield) *Quenstedtia sublevis* (Meek and Hayden), *Volsella jurassica* (Whitfield and Hovey)	6
3. Shale, medium gray, soft; weathers light gray	8
2. Limestone, dolomitic, nearly white; contains many thin layers of yellowish gray chert	4
1. Shale, calcareous, nodular, medium gray; overlies redbeds of the Spearfish formation with a sharp, irregular contact	3
Total thickness of the Gypsum Spring formation	21
Spearfish formation	

GYPSUM SPRING AND SUNDANCE FORMATIONS ON WEST SIDE OF STOCKADE BEAVER CREEK, 5 MILES NORTHEAST OF NEWCASTLE IN SEC. 18, T. 45 N., R. 60 W., WESTON COUNTY, WYOMING

	Feet
Sundance formation (part)	
Redwater shale member (part)	
12. Shale, gray and greenish gray; some layers are silty to sandy; contains many belemnites and some selenite; top not exposed	77
11. Sandstone, yellowish gray, very soft, fine-grained	5
10. Shale, gray, partly silty, soft	18
9. Sandstone, white, weathering light gray, fairly soft, thick- to thin-bedded, glauconitic; includes some thin beds of gray shale and shaly sandstone	7
Incomplete thickness of Redwater shale member	107
Lak member	
8. Siltstone and sandstone, mostly maroon; a 2-foot bed of greenish gray siltstone 15 feet below top; makes a sharp contact with overlying glauconitic sandstone	80
Hulett sandstone member	
7. Sandstone, white, massive, soft, very fine-grained; grades upward into siltstone and then into a foot of soft green shale	6
6. Siltstone, shale and some fine-grained sandstone, greenish gray to yellowish gray, weathering pink to buff	9
5. Sandstone, thick-bedded; forms sheer cliff; ripple-marked, light grayish yellow, weathering buff, glauconitic	30
4. Shale, sandy, interbedded with shaly to thin-bedded sandstone; shale is greenish gray; sandstone is yellow; grades into adjoining units; forms recess in cliff; contains *Camptonectes*	12
3. Sandstone, medium- to thick-bedded with some shaly partings, ripple-marked, light grayish yellow, weathering buff, glauconitic; grades into underlying unit	12
Total thickness of Hulett sandstone member	69
Stockade Beaver shale member	
2. Shale, dark gray, soft, fissile; contains some nodules of limestone in lower 10 feet and some limonitic shaly sandstone in lower foot; selenite crystals and *Camptonectes* present	63
Total thickness of Sundance formation	319
Gypsum Spring formation	
1. Gypsum, white, granular, bedded; forms low cliff; rests sharply on the slightly irregular surface of the redbeds of the Spearfish formation	8–12
Spearfish formation	

JURASSIC FORMATIONS ON EAST SIDE OF ELK MOUNTAIN, ABOUT 15 MILES SOUTHEAST OF NEWCASTLE, WYOMING, IN S. ½ OF SEC. 19, T. 4 S., R. 1 E., SOUTH DAKOTA

	Feet
Morrison formation (not measured)	
Sundance formation	
Redwater shale member	
14. Shale, dark gray to greenish gray, soft; several sandy beds in lower 30 feet; several fossiliferous limestone beds in upper 30 feet; selenite common; belemnites abundant in lower part; approximate thickness	150
13. Sandstone, medium- to thick-bedded, white, weathering grayish yellow, fine-grained; upper surface bears belemnites and gryphaeas	13
12. Sandstone, mostly greenish gray, glauconitic, soft	6
11. Siltstone, maroon, soft	3
10. Shale, sandy, and siltstone; some thin beds of gray sandstone in lower 5 feet; mostly gray to greenish gray, weathering yellowish gray	9
9. Sandstone, massive, white; has a sharp contact with underlying redbeds	7½
Total thickness of Redwater shale member	188½
Lak member	
8. Sandstone, massive, fine-grained, maroon, fairly hard	8
7. Sandstone, fine-grained, and siltstone, maroon, soft; includes a few thin beds of green siltstone	50
Total thickness of Lak member	58
Hulett sandstone member	
6. Shale, sandy, greenish gray; several ledges of slightly glauconitic gray sandstone from 15 to 20 feet above base	33
5. Sandstone, thin- to thick-bedded; upper 10 feet mostly thick-bedded, cliff-forming; light-grayish yellow, weathers buff, ripple-marked, fairly hard, glauconitic	22
Total thickness of Hulett sandstone member	55
Stockade Beaver shale member	
4. Shale, dark gray, soft; some limestone nodules in lower 5 feet; several beds of light greenish gray sandstone as much as 1 foot thick from 18 to 24 feet above base; lower foot yellowish. U.S.G.S. Mes. loc. 19560 in lower 5 feet has furnished *Arcticoceras* cf. *A. henryi* (Meek and Hayden), *Eumicrotis curta* (Hall), *Ostrea strigilecula* White, *Corbicellopsis? inornata* (Meek and Hayden), and *Quenstedtia sublevis* (Meek and Hayden)	65
3. Sandstone, white, granular; contains *Ostrea strigilecula* White on upper surface; possibly represents the Canyon Springs sandstone member	1
Total thickness of the Sundance formation	367+
Gypsum Spring formation	
2. Gypsum, massive, white, weathering yellowish white	4½
Nugget (?) sandstone	
1. Sandstone, massive, fairly hard, medium-grained, salmon-red, weathering brick-red; rests on somewhat darker and softer redbeds of the Spearfish formation with a slightly irregular contact	4½
Spearfish formation	

JURASSIC FORMATIONS ABOUT 3 MILES WEST-NORTHWEST OF MINNEKAHTA IN S. $\frac{1}{2}$ OF SEC. 11, T. 7 S., R. 3 E., SOUTH DAKOTA

	Feet
Morrison formation (not measured)	
Sundance formation (part)	
Redwater shale member (part)	
17. Shale, dark gray, soft, fissile; upper part has many ledges of limestone from a few inches to 2 feet thick; belemnites common near base. Overlain, apparently along a fault contact, by about 15 feet of fossiliferous gray limestone that grades up into hard, fine-grained white sandstone that is overlain by shale typical of the Morrison formation. Estimated thickness of the shale	80
16. Sandstone, shaly, light gray, glauconitic, ripple-marked	18
15. Sandstone, greenish gray, soft, glauconitic	9
Incomplete thickness of Redwater shale member	107
Lak member	
14. Siltstone, maroon, soft	18
13. Sandstone, medium-grained, maroon, massive	4
12. Siltstone, grayish green	5
11. Sandstone, fine-grained, and siltstone, maroon	6
10. Sandstone, medium-grained, salmon-pink, massive	12
9. Sandstone, fine-grained, and siltstone, maroon	15
Total thickness of Lak member	60
Hulett sandstone member	
8. Shale, medium gray to greenish gray	10
7. Sandstone, nearly white, medium-bedded at base, shaly in middle, and thin-bedded at top, medium- to fine-grained, ripple-marked, weathers light gray, glauconitic	22
Total thickness of Hulett sandstone member	32
Stockade Beaver shale member	
6. Shale, dark gray, some limonitic nodules and very thin layers of calcareous sandstone in lower 5 feet. Lower foot characterized by fossiliferous limonitic nodules and by subangular pebbles from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter of a very hard, dense metamorphic rock. U.S.G.S. Mes. loc. 19558 from lower 5 feet yielded *Eumicrotis curta* (Hall), *Corbicellopsis? inornata* (Meek and Hayden), *Quenstedtia sublevis* (Meek and Hayden), and *Astarte? fragilis* Meek and Hayden. U.S.G.S. Mes. loc. 19559 collected from the entire unit yielded *Pentacrinus asteriscus* Meek and Hayden, *Eumicrotis orbiculata* (Whitfield), *E. curta* (Hall), *Camptonectes extenuatus* (Meek and Hayden) *Corbicellopsis? inornata* (Meek and Hayden), *Ostrea* sp., and *Pachyteuthis* sp.	48
Canyon Springs sandstone member	
5. Sandstone, white, medium-bedded, medium-grained, contains many red specks; small oysters common	13
Total thickness of the Sundance formation	260
Nugget (?) sandstone	
4. Sandstone, salmon-colored, massive, cliff-forming but fairly soft, coarsely cross-bedded, medium- to fine-grained, some grains highly polished; some fine chert grit throughout, weathers brick-red; base somewhat irregular and bears some pitted and polished dark gray, chert-like pebbles; thickens westward and thins southward	21
3. Sandstone, yellow	3
2. Sandstone, yellow to salmon-colored, laminated, appears to thicken considerably toward the southwest	2
1. Sandstone, salmon-colored, massive, contains a few pitted and polished dark gray, chert-like pebbles as much as 2 inches in diameter, rests fairly evenly on the Spearfish formation	3
Total thickness of the Nugget (?) sandstone	29
Spearfish formation	

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 274-281, 1 FIG.

PALEOZOIC FORMATIONS NEAR CODY, PARK COUNTY, WYOMING[1]

T. F. STIPP[2]
Roswell, New Mexico

ABSTRACT

A well exposed section of Paleozoic strata ranging in age from Cambrian to Permian occurs in Shoshone River Canyon, 5 miles west of Cody. The section was measured and described in order to obtain information to facilitate well correlation in the Big Horn Basin. The measured section shows an average thickness of 3,200 feet. No Silurian strata have so far been recognized. In the Oregon Basin oil and gas field, 17 miles southeast of Shoshone Canyon, a recent well, drilled to the pre-Cambrian basement, penetrated a Paleozoic section, totaling approximately 3,000 feet in thickness. Examination of the well cores and bit cuttings showed the surface and well sections to be similar. A slight thinning of the section southeastward from the mountains is indicated. A correlation chart showing the two sections accompanies this paper.

INTRODUCTION

This paper describes and correlates formations ranging in age from Middle Cambrian to Permian, inclusive, that are exposed in Shoshone River Canyon, 5 miles west of Cody, Wyoming, and that have been drilled in the Oregon Basin oil field, 17 miles southeast of the canyon. The study was made as an aid in the administration of the oil and gas provisions of the Federal mineral-leasing laws, especially as geologists have disagreed about the age of the pre-Madison limestone strata drilled at Oregon Basin.

Columnar section A (Fig. 1) is based on measurements and descriptions herein. Columnar section B (Fig. 1) is based on a study of the records, bit-cuttings, and cores of Connaghan well No. 5, drilled by the Kirk Oil Company and the Pacific-Western Oil Corporation at Oregon Basin. This well was completed in December, 1945, stopping in pre-Cambrian igneous rocks at the total depth of 6,434 feet.

The names of formations below the Amsden used herein are those used, described historically, and correlated regionally by Lovering[3] 50 miles northwest of Shoshone River Canyon.

PALEOZOIC FORMATIONS IN SHOSHONE RIVER CANYON

EMBAR FORMATION (PERMIAN)

The following section of the lower four-fifths of the Embar formation was measured on the north wall of Shoshone River Canyon at its east entrance.

	Thickness in Feet
Limestone, buff, massive; contains a few nodules of chert; poorly exposed	30±
Limestone, pink or reddish; poorly exposed	3

[1] Manuscript received, July 8, 1946. Published by permission of the director of the Geological Survey.

[2] Geological Survey, United States Department of the Interior.

[3] T. S. Lovering, "The New World or Cooke City Mining District, Park County, Montana," *U. S. Geol. Survey Bull. 811* (1929), pp. 1-87.

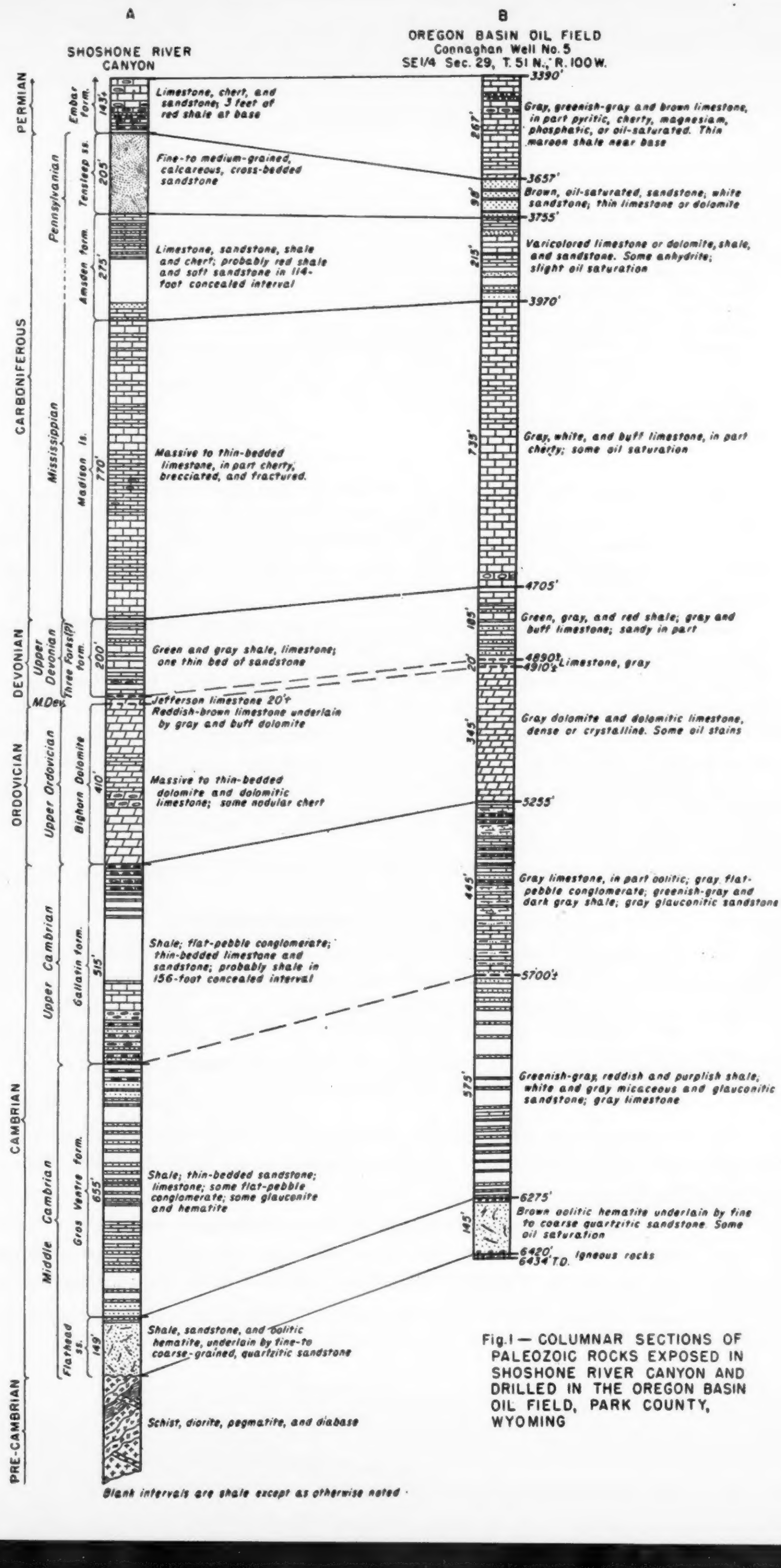


Fig. 1 — COLUMNAR SECTIONS OF PALEOZOIC ROCKS EXPOSED IN SHOSHONE RIVER CANYON AND DRILLED IN THE OREGON BASIN OIL FIELD, PARK COUNTY, WYOMING

	Thickness in Feet
Limestone, cream-colored, massive, fossiliferous; poorly exposed	30±
Limestone, gray, buff, cream-colored, mostly massive, cherty in part	26
Chert, nodular, and gray limestone	3
Sandstone, gray, calcareous, fine-grained	5
Chert, gray, nodular and massive, fractured	8
Limestone, gray, with nodules of gray chert	2
Limestone, cream-colored, soft, and some chert	1
Limestone, buff and cream-colored, massive to thin-bedded, chalky in part; contains concretions of chert and calcite	25
Chert, gray, nodular, with some gray limestone and shale	5
Limestone, buff, with concretions of chert and calcite	2
Shale, variegated, sandy in part	3
	143±

Beds similar and equivalent to the foregoing yield oil at Oregon Basin and at many other localities in the Big Horn and Wind River basins, Wyoming. In western Wyoming and contiguous parts of Utah, Idaho, and Montana, phosphatic shale, thin limestone, and chert of the same age make up the Phosphoria formation.

At DeMaris Springs in the bed of Shoshone River the thickness of the entire Embar formation is 140 feet. The top 50 feet of shale, calcareous shale, and thin-bedded, bluish or greenish gray limestone probably represents the greenish gray, brownish, reddish gypseous shale, thin bedded limestone, cherty dolomite, calcareous sandstone, and anhydrite that commonly occur at this horizon in outcrops and in deep wells in the Big Horn Basin and that are often called the Dinwoody formation. The rest of the Embar at DeMaris Springs is, in descending order, 82 feet of limestone, chert and sandstone and 8 feet of bluish gray, red-stained, thin-bedded shale.

On the slopes of near-by Cedar Mountain Johnson[4] measured 210 feet of Embar.

TENSLEEP SANDSTONE (PENNSYLVANIAN)

The Tensleep sandstone makes steep cliffs in the walls of Shoshone River Canyon. About 2½ miles northeast of Shoshone Dam its total thickness is 150 feet and just west of the dam it is 205 feet, as follows.

	Thickness in Feet
Sandstone, buff or light brown, white when unweathered, fine- to-medium-grained, cross-bedded, made up almost wholly of quartz grains	
Total thickness	205

The Tensleep yields oil at Oregon Basin; in fact, the Tensleep and its stratigraphic equivalents yield almost all of the Pennsylvanian oil in the Rocky Mountain region.

AMSDEN FORMATION (PENNSYLVANIAN AND MISSISSIPPIAN)

In Shoshone River Canyon—as elsewhere—the relatively soft beds of the Amsden formation are largely concealed by reddish soil on slopes between the

[4] G. Duncan Johnson, "Geology of the Mountain Uplift Transected by the Shoshone Canyon, Wyoming," *Jour. Geology*, Vol. 42, No. 8 (1934), p. 817.

overlying Tensleep sandstone and the underlying Madison limestone. Just west of Shoshone Dam, the Amsden is 225 feet thick and on the north side of Shoshone River Canyon it is 275 feet thick, as follows.

	Thickness in Feet
Limestone and sandstone, buff and gray, and a thin bed of light-green shale	32
Shale and sandstone, buff, and light-gray limestone; interbedded	27
Sandstone, purple	3
Limestone, gray, and purplish shale; interbedded	5
Limestone, gray; buff sandstone, and greenish gray shale; interbedded	38
Shale and sandstone, red and buff	5
Limestone, gray	2
Sandstone, buff	2
Limestone, gray, brecciated	2
Concealed, probably red shale and soft sandstone	114
Sandstone, gray, cherty	3
Sandstone and shale, purple	7
Sandstone, purple, cherty	6
Limestone and calcareous shale, purplish, mottled, thin-bedded	21
Sandstone, gray	5
Limestone, gray	1
Sandstone, greenish gray	2
Total thickness	275

The Amsden yields oil at two places in the Rocky Mountain region: Soap Creek and Gage domes, Montana.

MADISON LIMESTONE (LOWER MISSISSIPPIAN)

The Madison limestone forms impressive cliffs on both sides of Shoshone River Canyon, and measurements of all of it at four places there showed thicknesses ranging between 650 and 770 feet. The following 770-foot section was measured north of the highway bridge in the canyon.

	Thickness in Feet
Limestone, gray, massive to thin-bedded	75
Limestone, gray, chalky, thin-bedded	3
Limestone, gray, massive to thin-bedded; lower part brecciated	104
Limestone, gray, massive to thin-bedded, brecciated in places; contains secondary calcite in fractures	155
Limestone, brownish gray, massive to evenly-bedded, with a few nodules of chert	165
Limestone, gray, thick-bedded, somewhat brecciated, with secondary calcite along fracture planes	85
Limestone, gray, thin-bedded	31
Limestone, gray, lower half massive and upper half thinner-bedded; somewhat brecciated in upper half	134
Limestone, buff, even-bedded	18
Total thickness	770

The Madison yields oil at Oregon Basin, Garland, Kevin-Sunburst, and in a few other less important fields in Wyoming and Montana.

THREE FORKS (?) FORMATION (UPPER DEVONIAN)

Measurements of the Three Forks (?) formation at four places in Shoshone River Canyon ranged between 190 feet and 200 feet. The formation seemingly is

conformable with the overlying Madison limestone and the underlying Jefferson limestone. Inasmuch as correlation of these strata is based on lithology it seems desirable to show a question mark (?) after the term Three Forks. The following section of all the Three Forks (?) was measured northwest of the highway bridge in the canyon.

	Thickness in Feet
Shale, greenish gray, soft	10
Limestone, buff, thin-bedded, slabby	16
Limestone, buff, thin-bedded, and yellowish green shale; interbedded	16
Limestone, buff, thin-bedded	11
Shale and limestone, yellowish green, thin-bedded	5
Sandstone, buff	½
Limestone, gray, massive	5
Limestone, buff, massive to thin-bedded, and yellowish green shale; interbedded	86
Limestone, and shale, buff, thin-bedded, and platy shale; thicker limestones are somewhat cherty	33
Limestone, gray, thin-bedded	6½
Limestone, buff	2
Shale, greenish gray, and buff, platy limestone; interbedded	9
Total thickness	200

In general, the limestones have a distinct orange tint; in fact Lovering[5] states that in the New World or Cooke City mining district the upper half of the Three Forks formation is bright-red and green fissile shale and thin-bedded purple limestone and that the lower half is gray and purple limestone, light-brown sandy limestone, shaly limestone, and gray and purple shale.

JEFFERSON LIMESTONE (MIDDLE DEVONIAN)

Although Johnson[6] included all the cliff-forming dolomites between his Gallatin and Three Forks in his Bighorn dolomite, he described a single occurrence of reddish limestone at the top of his Bighorn which yielded no fossils, "but probably can be interpreted as an early Devonian filling of a channel in the Bighorn, like those described by Hughes[7] as 'basal Jefferson' along the Beartooth Mountain Front."

Five feet above the north edge of the highway at the west end of the first highway tunnel, about ½ mile west of Shoshone Dam, the writer collected *Atrypa* aff. *A. missouriensis* Miller from massive to thin-bedded dolomitic limestone that weathers reddish brown. As Edwin Kirk[8] states that this fossil is known over a large area, and is probably a good Jefferson marker, 20± feet of limestone and dolomite is designated Jefferson limestone herein. However, the exact upper and lower limits of the Jefferson could not be determined at this locality.

[5] *Op. cit.*, p. 28.

[6] *Op. cit.*, p. 817.

[7] R. V. Hughes, "The Geology of the Beartooth Mountain Front in Park County, Wyoming," *Proc. Nat. Acad. Sci.*, Vol. 19 (1933), pp. 239–53.

[8] Letter from John B. Reeside, Jr., July 17, 1945.

In the New World district, Lovering[9] measured 125 feet of Jefferson, noting an apparent marked erosional unconformity between it and the underlying Bighorn dolomite in the southwestern part of the district.

BIGHORN DOLOMITE (UPPER ORDOVICIAN)

The Bighorn dolomite is about 410 feet thick in Shoshone River Canyon. The following section was measured on the north wall of the canyon near the highway bridge.

	Thickness in Feet
Dolomite, gray and buff, massive to thin-bedded; nodules of chert in upper part; some greenish gray, thin limestone or dolomite beds in lower part	115
Dolomite, white, some thin beds are pink, massive to thin-bedded, lower part much fractured; 10 feet of gray, massive dolomite near the middle; some beds weather chalky	110
Dolomite, gray and buff, massive, with nodules of chert in upper part	185
Total thickness	410

The upper and lower members of the Bighorn crop out in almost vertical cliffs. The middle member, however, is less resistant and commonly concealed.

GALLATIN FORMATION (UPPER CAMBRIAN)

The Gallatin formation seemingly is conformable on the Gros Ventre formation and contains many flat-pebble conglomerates with ellipsoidal pebbles $\frac{1}{2}$ inch to 6 inches in diameter and $\frac{1}{4}$ inch to 1 inch thick that commonly lie parallel with the bedding planes, or in some places at any angle to them.

The following section was measured on the north side of Shoshone Canyon.

	Thickness in Feet
Shale, bluish gray, with gray, flat-pebble conglomerate and gray, locally pyritic limestone; all thin-bedded and interbedded; shale predominates, especially in the lower part	145
Concealed, chiefly shale (?)	156
Limestone, buff, thin-bedded	4
Limestone, buff, massive, oölitic, fossiliferous in part, forms top of vertical cliff	24
Limestone, buff, and buff flat-pebble conglomerate; dark and greenish gray shale in lower one-third; all thin-bedded and interbedded; limestone predominates, forms a vertical cliff	96
Flat-pebble conglomerate, gray and buff; brown, thin-bedded sandstone; gray, thin-bedded limestone; dark gray, platy shale; all interbedded; maximum thickness of single beds is 2–3 feet; forms low cliffs	90
Total thickness	515

Around the Beartooth Range in south-central Montana and along the southeast front of the Absaroka Range, south to Shoshone River Canyon, Dorf and Lochman[10] eliminated the term Gallatin, substituting therefore three new forma-

[9] *Op. cit.*, p. 27.

[10] Erling Dorf and Christina Lochman, "Upper Cambrian Formations in Southern Montana," *Bull. Geol. Soc. America*, Vol. 51, No. 4 (1940), pp. 541–56.

tional units. Miller,[11] however, states that the Cambrian sequence in the Shoshone River Canyon is divisible into the Flathead, Gros Ventre, and Gallatin formations. A discussion of the confusion in Cambrian nomenclature in this region has been published by Deiss.[12]

GROS VENTRE FORMATION (MIDDLE CAMBRIAN)

The Gros Ventre formation seemingly overlies the Flathead sandstone conformably and is composed largely of greenish gray shale, with some interbedded sandstone and limestone. The following section of the Gros Ventre was measured on the north side of Shoshone River Canyon about a mile northeast of Shoshone Dam.

	Thickness in Feet
Shale, greenish gray, platy; brown sandstone, in beds averaging about one inch thick; all interbedded with thin beds of flat-pebble conglomerate that are more abundant toward the top	193
Shale, greenish gray, platv, with interbedded reddish brown or maroon sandstone. The sandstone is in three conspicuous beds each 3 to 4 feet thick; a 4-foot marron, glauconitic, and hematitic sandstone is at the top	60
Shale, greenish gray, platy, interbedded with lesser amounts of brown and gray, thin-bedded, platy sandstone	153
Limestone, gray, thin-bedded, weathers brown, cliff-forming	28
Shale, brown, micaceous, and a small amount of gray sandstone	14
Shale, limestone, and sandstone, greenish gray, and light brown, thin-bedded, and interbedded	11
Limestone, brown, thin-bedded, containing small, round, flat pebbles and a few thin beds of sandstone	7
Shale, greenish gray, platy, and beds of brown, thin-bedded sandstone that increase in number upward	166
Shale, green, soft, and brown and green glauconitic sandstone; thin-bedded green sandstone and hematite in lower 10 feet; transitional into the Flathead	23
Total thickness	655

FLATHEAD SANDSTONE (MIDDLE CAMBRIAN)

The Flathead sandstone lies on a moderately uneven surface of pre-Cambrian igneous rocks in the inner gorge of Shoshone River Canyon. As a thin Flathead section was deposited over higher parts of the pre-Cambrian erosion surface and a thicker section over lower parts, the sandstone is 90 to 149 feet thick in the canyon. The following section was measured on the north side of the canyon about one mile northeast of Shoshone Dam.

	Thickness in Feet
Shale and sandstone, greenish gray, thin-bedded, with thin beds of dark red oölitic hematite at the top; weathers to red soil; transitional into the Gros Ventre	5
Sandstone, brown, fine to coarse-grained, hard, quartzitic, even-bedded	32
Sandstone, gray and purple mottled, fine to coarse-grained, hard, quartzitic	1
Sandstone, gray, brown, and reddish brown, fine to coarse-grained, quartzitic, thin-bedded to massive, hard	21

[11] B. Maxwell Miller, "Cambrian Stratigraphy of Northwestern Wyoming," *Jour. Geol.*, Vol. 44, No. 2 (1936), p. 139.

[12] Charles Deiss, "Revision of Type Cambrian Formations and Sections of Montana and Yellowstone National Park," *Bull. Geol. Soc. America*, Vol. 47, No. 8 (1936), pp. 1257–1342.

	Thickness in Feet
Sandstone, gray and brown, fine to coarse-grained, hard, quartzitic, thin-bedded to massive; massive beds are cross-bedded; rests on a smooth surface of pre-Cambrian pegmatitic granite	90
Total thickness	149

CORRELATION OF EXPOSED AND DRILLED FORMATIONS (FIG. 1)

Although some minor stratigraphic divisions exposed in Shoshone River Canyon could not be recognized in bit cuttings from the Connaghan well No. 5 at Oregon Basin, the exposed and drilled formations are very similar. A total of the average thicknesses of exposed formations is 3,200 feet and the thickness of equivalent drilled formations is 3,030 feet, less a minor correction for a dip of 5° or less. Columnar section A is longer than columnar section B, because the former largely represents the maximum thicknesses of exposed formations.

The Embar formation, Tensleep sandstone, Amsden formation, and Madison limestone are lithologically distinct in this general area and present no difficult correlation problems.

Bit cuttings from the Three Forks (?) formation included red shale not seen at the outcrop. Otherwise the exposed and drilled Three Forks (?) are similar.

As the upper and lower limits of the Jefferson limestone could not be determined at the outcrop and in the well, the formation has been given an arbitrary thickness of 20 feet in both.

Outcrops and bit cuttings of the Bighorn dolomite are similar.

Conglomerate with rounded pebbles are less numerous in bit cuttings of the Gallatin formation than at its outcrop. In other respects, however, the exposed and drilled Gallatin are similar. The top of the Gallatin was drawn at the outcrop and in the well where massive dolomite lies on shale and flat-pebble conglomerate.

In the well, the contact between the Gallatin formation and the Gros Ventre formation has been placed arbitrarily at a depth of 5,700 feet, because the mingling of bit cuttings from both formations prevented an accurate determination of their contact.

The top of the Flathead sandstone was drawn at the outcrop and in the well at the top of abundant, sandy, oölitic hematite, beneath which occurs white, coarse sandstone grading downward into conglomerate containing white, rounded pebbles as much as ½ inch in diameter. The Flathead also contains much feldspar derived from pre-Cambrian pegmatites. Of especial interest is the presence of some oil saturation in the Flathead in the well.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 282-292, 1 FIG.

PALEOZOIC SEAWAYS IN WESTERN ARIZONA[1]

EDWIN D. McKEE[2]
Flagstaff, Arizona

ABSTRACT

In the New Water Mountains of western Arizona, Cretaceous (?) conglomerate beds composed of boulders and other gravels derived locally from pre-Mesozoic rocks, give new evidence of the former distribution of Paleozoic strata in this area. Rocks of Cambrian, Devonian, Mississippian, Pennsylvanian (?), and Permian age are recognized in the conglomerate. Their relationship to strata of corresponding age in the well known formations of both northern and southern Arizona is discussed.

INTRODUCTION

There are few records of Paleozoic strata in central western or southwestern Arizona. Crystalline rocks that form the bulk of the mountain ranges in this region, as shown on the Geologic Map of Arizona,[3] have, for the most part, been assumed to be pre-Cambrian in age, although later work has indicated that the sodic granite and some of the metamorphic rocks may be Mesozoic or early Tertiary.[4] Cretaceous rocks, more or less metamorphosed, have been recognized in numerous ranges. In contrast, data pertaining to Paleozoic formations are limited to references by Darton[5] to "limestones of Carboniferous age" found in five of the mountain ranges, and to mention by Wilson[6] and by Stoyanow[7] of upper Paleozoic fossils included in post-Permian conglomerate gravels of this region.

The present study, made in the New Water Mountains of western Arizona, is of gravels derived from rocks of various pre-Mesozoic periods and preserved as conglomerates in Cretaceous (?) strata. Since these gravels were locally derived and little transported, as indicated by the size and shape of many individuals, they furnish data regarding the former distribution of Paleozoic rocks in the region. The strata in which they occur form a low hill at the southern end of the

[1] Manuscript received, June 24, 1946.

[2] Museum of Northern Arizona. The writer gratefully acknowledges the helpful suggestions and assistance of Eldred D. Wilson, who accompanied him in the field and went over the manuscript. For criticizing the manuscript thanks are also due to B. S. Butler, J. I. Snow, and Halka Pattison. Cambrian fossils were kindly examined by G. A. Cooper and Christina Lochman, and thin sections of the sandstones studied by M. N. Short.

[3] Prepared by Arizona Bureau of Mines in cooperation with the United States Geological Survey, 1924.

[4] Kirk Bryan, "The Papago Country, Arizona," *U. S. Geol. Survey Water-Supply Paper 499* (1925), pp. 58–59.

Eldred D. Wilson, "Geology and Mineral Deposits of Southern Yuma County, Arizona," *Univ. Arizona Bur. Mines Bull. 134* (1933), p. 236.

[5] N. H. Darton, "A Résumé of Arizona Geology," *Univ. Arizona Bur. Mines Bull. 119* (1925), pp. 215–23.

[6] Eldred D. Wilson, *op. cit.*, p. 80.

[7] A. A. Stoyanow, "Paleozoic Paleogeography of Arizona," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1278.

mountain range, about 15 miles southeast of Quartzite. Here a thick series of beds has been folded and faulted so that it is repeated in various ridges forming the hill, and the strata now stand at a high angle. The importance of these beds

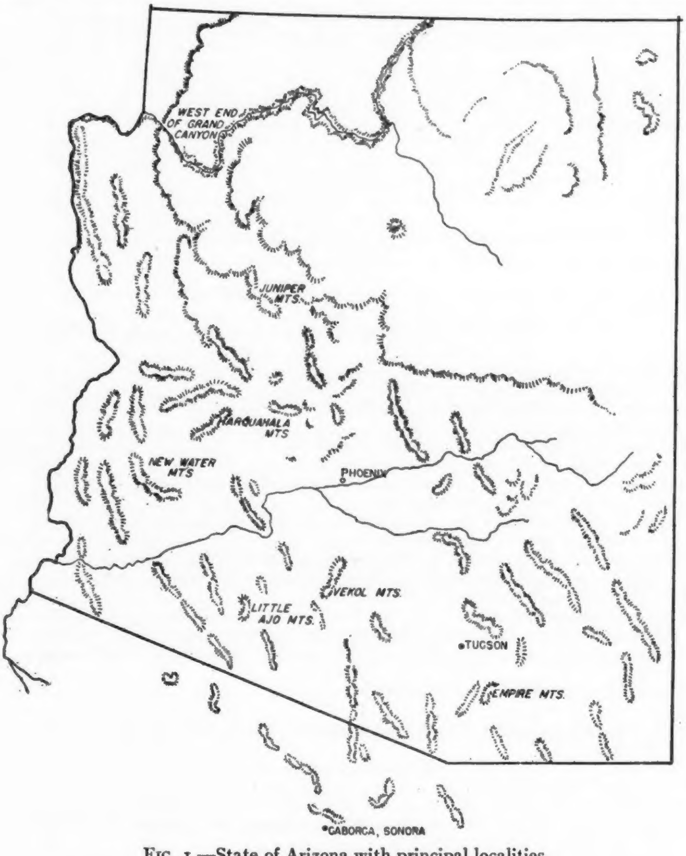


FIG. 1.—State of Arizona with principal localities referred to in text.

was recognized by Wilson in 1933.[8] A visit to the section was made by Wilson and E. D. McKee in January, 1944, followed by the present study made in December of the same year.

DESCRIPTION OF STRATA CONTAINING GRAVELS

The Cretaceous (?) strata of the New Water Mountains are approximately 2,000 feet thick where measured on the northwesternmost ridge of the hill. This

[8] Eldred D. Wilson, *op. cit.*, p. 80.

figure is only a minimum, however, for the lower limit of the section is concealed beneath alluvium forming the valley fill, and the highest beds exposed lie in the partly eroded axis of a syncline. The original thickness may have been far greater.

SECTION OF CRETACEOUS (?) STRATA, NEW WATER MOUNTAINS, ARIZONA
(Northeast ridge of southernmost hill. Beds strike N. 60° E.; dip 75–90° SE.)

	Feet
Axis of syncline: no higher beds exposed	
1. Claystone: light reddish gray, silty, shaly, brittle; weathers same	10.0
2. Sandstone: light brownish gray, mostly medium-grained (poorly sorted), arkosic (feldspars light brown), calcareous; contains scattered pebbles up to ½ inch; contains plant (wood) impressions; shows large (4–5 inches) asymmetrical ripple marks; weathers with black varnish; forms ledge	1.5
3. Claystone: light reddish gray, shaly; like No. 1; beds 6–10 feet thick; alternates with:	
Sandstone and siltstone: medium gray, arkosic; like No. 2; beds thin (6–12 inches); weathers weak red, resistant	
Total	42.0
4. Sandstone: light brownish gray, mostly medium-grained, very arkosic; like No. 2	2.0
5. Claystone: light reddish gray, shaly; like No. 1	15.0
6. Limestone: brownish gray, aphanitic; weathers dark yellowish brown with laminae etched out	1.0
Concealed: probably claystone	2.0
7. Sandstone: light brownish gray, arkosic; like No. 2	1.0
8. Claystone: light reddish gray, shaly; like No. 1; contains some thin, gray, quartzitic sandstone beds	11.0
9. Sandstone: light brownish gray, arkosic; like No. 2	2.0
10. Claystone: light reddish gray, shaly; like No. 1	30.0
11. Sandstone: brownish gray, fine-grained, calcareous; contains plant fragments; weathers with brownish black varnish	2.0
12. Claystone: light reddish gray, shaly; like No. 1; includes some thin beds of light brownish gray, arkosic sandstone like No. 2	15.0
13. Sandstone: dark gray, medium-grained, very calcareous, arkosic (feldspar grains large); beds 2–24 inches thick; contains scattered clay partings and pellets; weathers brownish black; forms resistant ledge	11.0
14. Claystone: light reddish gray, shaly; like No. 1; contains ovoid and irregular concretions of mudstone and iron oxides with pyrite cubes in centers; contains abundant plant remains (poorly preserved bark and leaf impressions); interfingered with:	
Siltstone: light brownish gray, thin-bedded	
Total	31.0
15. Sandstone: dark gray, very calcareous, thin-bedded (1–6 inches); like No. 13; alternates with:	
Claystone: light reddish gray, shaly; beds 1–3 feet thick	
Total forms resistant ridge	36.0
16. Sandstone and claystone: like No. 15 but with more claystone; forms slope	30.0
17. Claystone: light reddish gray (locally pale red); contains thin gray sandstone beds near top and bottom; forms valley	30.0
18. Limestone: medium gray (locally with reddish gray bands), aphanitic, argillaceous; main beds thick (3–4 feet), beds near top and bottom thinner (2–12 inches); weathers with dark brown varnish; forms ledge	13.0
19. Siltstone: weak red, argillaceous, shaly; beds thin and flat; weathers very pale reddish brown	8.0
20. Conglomerate	12.0
Matrix: medium gray, arkosic sandstone	
Gravel size: maximum 3 feet; mostly 3 inches and less	
Gravel shape: mostly well rounded, some angular, limestones very irregular	
Gravel composition: quartzite, limestone, granite	
21. Claystone: light reddish gray, shaly; like No. 1; grades downward through pale gray, fine-grained, arkosic sandstone to coarse sandstone, then to fine sandstone and claystone; forms valley	9.0

SECTION OF CRETACEOUS (?) STRATA, NEW WATER MOUNTAINS, ARIZONA—*Continued*

	Feet
22. Conglomerate: like No. 20 but with more large boulders	26.0
Gravel size: maximum 8 feet Gravel shape: well rounded or angular Gravel composition: quartzite, silty limestone, algal limestone, crystalline limestone	
23. Claystone and siltstone: light olive-gray, shaly; contains plant impressions (stems and willow-like leaves); upper contact shows relief of 1–2 feet; forms depression	12.0
24. Sandstone: medium gray, medium-grained, arkosic; like No. 2 but contains few coarse grains; beds ½–2 feet thick; contains a few claystone lenses; contains conglomerate near base; weathers rough with weak brown to light brown stain	11.0
25. Conglomerate: like No. 20	372.0
Gravel size: mostly 1–4 inches, many limestone boulders 3–4 feet Gravel shape: well rounded to angular Gravel composition: crinoidal limestone, cherty limestone, silty limestone, massive quartzite, thin-bedded quartzite, granite (rare), dolomite (rare)	
26. Sandstone: weak reddish brown, argillaceous, calcareous; grades upward into conglomerate (No. 25)	3.0
27. Sandstone: light olive-gray, arkosic; like No. 2	4.0
28. Conglomerate: like No. 20 but upper 4 feet largely light olive-gray, arkosic sandstone with scattered large blocks and boulders	54.0
Gravel size: mostly 3 inches and less Gravel shape: pebbles mostly rounded; boulders rounded to angular Gravel composition: dominantly quartzite and limestone; coarse-grained granite abundant	
29. Sandstone: light olive-gray, arkosic; like No. 2; beds 2–10 inches thick	16.0
30. Conglomerate: like No. 20	342.0
Gravel size: mostly small (less than 1 inch) in upper 30 feet; commonly 2–7 feet (maximum 10 feet) in main part of unit; poorly sorted Gravel shape: small pebbles angular; boulders angular to rounded Gravel composition: quartzite, limestone, some dolomite	
31. Sandstone: brownish gray, arkosic; like No. 2 but with more coarse grains and locally conglomeratic; weathers with weak brown varnish	42.0
32. Claystone: reddish gray, shaly; like No. 1; bed of conglomeratic sandstone in middle	34.0
33. Conglomerate: like No. 20	120.0
Gravel size: maximum 10 feet Gravel composition: mostly quartzites and limestones	
34. Sandstone: light brownish gray, like No. 2; shaly near top, massive at base	6.0
35. Conglomerate	3.0
Gravel size: mostly 1 inch or less Gravel shape: angular to rounded	
36. Siltstone: reddish gray, platy, hard; weathers pale brown, spotted with weak red	14.0
37. Conglomerate: like No. 35	38.0
38. Claystone: light reddish gray, shaly; like No. 1; partly concealed	48.0
39. Sandstone: light brownish gray, arkosic; like No. 2 but friable and of more uniform grain size	2.0
40. Claystone: light reddish gray; like No. 1	7.0
41. Conglomerate: like No. 35 but containing some coarser gravel	35.0
42. Siltstone: reddish gray, platy, hard; like No. 36	13.0
43. Conglomerate: like No. 20	300.0
Concealed	102.0
44. Conglomerate	15.0+
Matrix: light olive-gray, argillaceous sandstone Gravel size: mostly less than 2 inches Gravel shape: mostly rounded, some angular Gravel composition: mostly coarse-grained igneous rocks, quartzite, and some limestone	
Total	1,933.5

Concealed

The rocks as shown in measured section are of three main types: (1) light reddish gray,[9] shaly claystone, (2) light brownish gray to dark gray arkosic sandstone, and (3) conglomerate with an arkosic matrix. Beds of each type are repeated many times in the section, although the conglomerate units alone account for most of the thickness. Differences in topographic expression resulting from a preponderance of one or another rock type in various parts of the formation make possible the recognition of four major members or subdivisions. These are an upper weak member composed of alternating claystone and sandstone beds (1–19);[10] an upper massive, resistant member formed largely of conglomerates (20–33); a lower weak member of claystones, sandstones, and small pebble conglomerates (34–42); and a basal, massive member composed of coarse conglomerates (43–44).

The light reddish gray claystones represent accumulations of very fine detrital material, many samples not including any particles up to silt size. Elsewhere they show gradation into arkosic siltstones or fine sandstones. They are notably brittle but the tendency toward shaly splitting is not well developed. An argillaceous odor is marked. These claystones occur as units from a few inches to thirty or forty feet in thickness. Some of them contain fragmentary plant impressions including leaves and bark; one unit contains ovoid and irregular concretions of mudstone and iron oxides with pseudomorphs of pyrite serving as nuclei.

Sandstones in the Cretaceous (?) strata are composed chiefly of detrital quartz (60–75 per cent), but also contain many light to dark gray and some pale red feldspar grains. Orthoclase and plagioclase form up to 25 per cent of the rock, and fragments of calcite up to 5 per cent. Hematite is scarce. Few grains of any mineral are rounded, and most of the feldspars show fresh cleavage faces, although some orthoclase has altered to sericite. As a result of poor sorting, grain size varies from bed to bed and commonly within beds. Individual grains are, for the most part, firmly cemented together, and the weathered rock resembles quartzite. In thickness, beds range from $\frac{1}{4}$ inch or less to several inches.

The conglomerates are very striking both because of their massive character and because of the wide variety in color, type, and size of the included gravels. Boulders up to 10 feet in diameter are found, and those ranging between 1 and 5 feet are common. Some beds, on the other hand, contain gravels of pebble or smaller size only. These gravels are, for the most part, well rounded, whereas the larger sizes are mostly in the form of blocks and in many cases show very little rounding. A large percentage of the gravels are limestone, many are quartzite and dolomite, and a moderate number, especially in the lower beds, are granite.

The exact age of these beds has not been established. They are definitely younger than Paleozoic as shown by middle Permian fossils in some of the included boulders. They can scarcely be more recent than middle Tertiary consider-

[9] All color descriptions are based on "Preliminary Color Standards and Color Names for Soils," *U. S. Dept. Agriculture Misc. Pub. 425* (1941).

[10] Numbers refer to beds in measured section.

ing the long history of post-conglomerate crustal disturbance and erosion that is represented in this area. Triassic or Jurassic age seems improbable as rocks of these periods are not known to occur elsewhere in the region. Cretaceous, Early or Middle Tertiary therefore seem the most likely ages.

In favor of Middle Tertiary age is the apparent similarity between the conglomerate beds of the New Water Mountains and the Locomotive fanglomerate of the Ajo area, described by Gilluly[11] and tentatively assigned by him to this age. His conclusion is based largely on an interfingering of the fanglomerate with Ajo volcanics, however, and was not considered as definite by him.

Lithologically the claystones and siltstones of the New Water Mountain series resemble closely continental deposits of known Cretaceous age found in many parts of southern Arizona. On this basis, Wilson[12] referred to the beds as Cretaceous (?) and that procedure is followed in this paper. Unfortunately the plant remains that have been found are not sufficiently well preserved to be useful in dating the rocks.

ENVIRONMENT OF DEPOSITION

Certain features of the environment of deposition represented by the Cretaceous (?) strata are at once apparent. The large size of many boulders and the angularity of the blocks indicate that they were derived from mountains in the immediate vicinity. These mountains, furthermore, must have been formed of rocks representing most of the Paleozoic periods as well as granites and schists of pre-Cambrian age. The latter types were exposed to erosion first in this area, apparently, for they are dominant in the basal conglomerate beds and are increasingly scarce above, whereas rocks derived from Paleozoic strata constitute most of the gravels in the middle and upper beds.

Although some of the light reddish gray claystone beds are silty, many others contain only particles of the finest size, probably deposited colloidally in pools or other shallow-water bodies. Alternating with these are beds of arkosic sandstone and coarser detrital materials, indicating times of greater stream activity and of current action. Plant remains suggest a continental environment.

Climatic conditions are difficult to determine because erosion in near-by hills with rapid transportation and burial, inferred on the basis of boulder size and shape, would account for many of the features commonly attributed to an arid environment. Even so, the great abundance of fresh angular feldspars and of detrital calcite, and the red color of the claystones suggest that the climate was not humid. That some of the orthoclase has altered into sericite, whereas all of the plagioclase is fresh, even in the same specimens, probably indicates separate sources for these minerals. Nodules containing clusters of pyrite crystal pseudomorphs, among some of the claystones, suggest local areas of stagnant waters where the activity of sulphate-reducing bacteria was prominent.

[11] James Gilluly, "Geology and Ore Deposits of the Ajo Quadrangle, Arizona," *Univ. Arizona Bur. Mines Bull. 141* (1937), pp. 43–45.

[12] Eldred D. Wilson, *op. cit.*, p. 80.

GRAVELS FROM CAMBRIAN STRATA

Among the boulders and other gravels in the conglomerate beds, at least three types appear to have been derived from pre-existing Cambrian strata of this area. The most common of these is a massive, dark gray limestone that is mottled with weak reddish brown or light yellowish brown and weathers light olive-gray with a rough, pitted surface. This type is lithologically similar to the Middle Cambrian Muav Limestone of Grand Canyon and contains fossils of similar age including *Glossopleura* sp., *Hyolithes* sp., and sponge spicules.

A second distinctive limestone of Cambrian aspect incorporated in the conglomerate is dark brownish gray, aphanitic, and thick-bedded, and contains spheres of *Girvanella*, 3 to 6 mm. in diameter, mostly filled with fine-grained black calcite or yellow-brown dolomite. The limestone contains some trilobite fragments but generically identifiable fossils have not been found in it. Similar *Girvanella* limestone is reported[13] from north of this area in the Muav limestone of Grand Canyon and from the Lower Cambrian of southern Nevada. Recently *Girvanellas* have also been found at the south, in Middle Cambrian strata of northwestern Sonora.[14]

Many of the quartzite boulders in the conglomerate appear to have been derived from Cambrian strata. They are predominantly dark brownish gray and medium- to thick-bedded. Some include very coarse quartz grains and, in a few cases, they contain shell fragments. A weak brown to black varnish develops with weathering. They have distinctive appearance and contrast with the fine-, even-grained quartzites of probable Permian age that weather into flat slabs. Lithologically they resemble the basal Cambrian quartzites such as the Troy and Tapeats found throughout much of the Cordilleran basin.

Strata of Cambrian age have not previously been recorded from this part of Arizona, but are known to occur in the Harquahala Mountains, 40 miles farther east, where detailed studies of the structure are being made by Eldred Wilson. In the Harquahala section as in Cambrian sections farther north, fissile light olive-gray shales overlie the basal quartzites. The only recognizable fossil yet found here is *Glossopleura* sp., but worm borings and shell fragments are not uncommon.

The lithologic similarity between Cambrian rocks of the New Water and Harquahala mountains and those of the Grand Canyon suggest a close correlation between these areas. The presence of *Glossopleura* in both places tends to confirm this and likewise to indicate a correlation with the Cambrian section in northwestern Sonora, where that genus has also been found.[15] Thus, it seems definite that in early Middle Cambrian time a seaway was continuous from western Mexico north through Arizona into the Grand Canyon area.

[13] Edwin D. McKee, "Cambrian History of the Grand Canyon Region," *Carnegie Inst. Washington Pub. 563* (1945), pp. 62–64.

[14] G. Arthur Cooper and Alberto R. V. Arellano, "Stratigraphy near Caborca, Northwest Sonora, Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 4 (April, 1946), p. 610.

[15] A. A. Stoyanow, *op. cit.*, p. 1263.
G. Arthur Cooper and Alberto R. V. Arellano, *op. cit.*, pp. 609–10.

GRAVELS FROM DEVONIAN STRATA

In the New Water Mountain section several conglomerate beds contain boulders and smaller gravels apparently derived from Devonian strata. Lithologically they resemble certain Devonian rocks found in western Grand Canyon and in central Arizona. They are composed of hard, fine-grained, dark gray dolomites that weather with rough, silty, pale brown surfaces. In one specimen was found a group of brachiopods of the genus *Atrypa*.

Insofar as is known this is the first record of Devonian strata in west-central Arizona. In the Harquahala Mountains on the east, lithologically similar rocks, doubtless also Devonian in age, occur below definitely determined Mississippian limestones, but as yet no fossils have been found in these beds.

It seems probable that the Late Devonian seaway that covered most of the Grand Canyon area and extended southeastward into central Arizona also covered this western part of the state. Furthermore, the seaway may have extended southeastward from the New Water Mountain area to connect with the Martin limestone of southern Arizona. Cutcrops of the latter are stated by Darton[16] to be in the Vekol Mountains, about 137 miles southeast, and gravels containing a Martin fauna are reported by Gilluly[17] from a fanglomerate near Ajo, about 45 miles closer. Thus, a connecting seaway through western Arizona may have been present in Devonian time in addition to that across the eastern part of the state demonstrated through the work of Huddle and Dobrovolny.[18] Devonian strata in northwestern Sonora, Mexico, noted by Cooper and Arellano[19] suggest a further extension of the seaway southward.

GRAVELS FROM MISSISSIPPIAN STRATA

Coarse-grained, very light brownish gray, thick-bedded limestone of Mississippian age is abundantly represented as gravels in nearly all of the conglomerate beds in the New Water Mountain section. These gravels characteristically weather into massive, pale gray, solution-pitted blocks. Some boulders with diameters up to 10 feet have been noted. Many specimens contain abundant crinoid fragments and some are sufficiently full of these joints to be termed crinoidal limestones. An undetermined horn coral and *Spirifer centronatus* have been found.

The presence of Mississippian strata in west central Arizona was first suggested by Darton,[20] who refers to "Carboniferous fossils," and to "limestone

[16] N. H. Darton, *op. cit.*, p. 264.

[17] James Gilluly, *op. cit.*, p. 42.

[18] J. W. Huddle and E. Dobrovolny, "Late Paleozoic Stratigraphy of Central and Northeastern Arizona," *U. S. Geol. Survey Prelim. Chart 10*, Oil and Gas Investig. Ser. (1945).

[19] G. Arthur Cooper and Alberto R. V. Arellano, *op. cit.*, p. 610.

[20] N. H. Darton, *op. cit.*, pp. 215–23.

closely resembling Carboniferous strata" which he found in five of the mountain ranges in this region. Some of these references may have been to Permian beds or Permian fossils that likewise occur in the area, but probably Darton also had in mind the typical Mississippian deposits that are exposed in the Harquahala and other ranges. Additional references to the probable occurrence of the Mississippian strata in western Arizona are given by Stoyanow.[21]

Limestones of Mississippian age found in the conglomerates of the New Water Mountains are lithologically similar to those forming parts of the Redwall limestone of northern Arizona, especially subdivision B of Noble[22] or member III of Gutschick.[23] In southern Arizona comparable granular limestones occur in parts of the Escabrosa which, according to Huddle and Dobrovolny,[24] is continuous with the Redwall through the eastern part of the state.

The nearest exposure of the Redwall limestone is in the Juniper Mountains, about 150 miles north northeast. The nearest Escabrosa outcrop recorded is in the Vekol Mountains 137 miles southeast, although Gilluly[25] refers to gravels apparently formed from this limestone, in a fanglomerate near the Little Ajo Mountains, 115 miles south southeast. Thus, Mississippian deposits of the New Water Mountain area probably were once continuous with both the Redwall and Escabrosa limestones as indicated by their known distribution and by their similarity in rock character and fossil content.

GRAVELS FROM PENNSYLVANIAN (?) STRATA

Boulders and blocks composed of aphanitic, very pale reddish brown limestone which weathers with a light brownish gray, silty surface occur in several of the conglomerate beds. Some specimens show cross-lamination where the silty layers have been etched into relief. This distinctive type of rock is essentially identical with that forming certain beds in the Callville limestone, western equivalent of the Supai formation, in northern Arizona. A comparison of hand specimens from the two areas shows no recognizable differences, so despite the fact that fossils are not available for correlation, reference to a common source seems justifiable. If this lithologic comparison is sound, then the age is either late Pennsylvanian or early Permian.

GRAVELS FROM PERMIAN STRATA

At least three types of rock represented in the gravels of the Cretaceous (?) conglomerate appear to have been derived from Permian strata. Two are lime-

[21] A. A. Stoyanow, *op. cit.*, p. 1272.

[22] L. F. Noble, "A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail," *U. S. Geol. Survey Prof. Paper 131B* (1922), p. 54.

[23] R. C. Gutschick, "The Redwall Limestone (Mississippian) of Yavapai County, Arizona," *Plateau*, Vol. 16, No. 1 (1943), p. 5.

[24] J. W. Huddle and E. Dobrovolny, *op. cit.*

[25] J. Gilluly, *op. cit.*, p. 40.

stones containing diagnostic fossils; the third is a quartzite assigned on the basis of lithologic similarities.

The most common of these rock types is a dark gray, fossiliferous limestone that weathers to a medium olive-gray, massive, rough surface. It is partly aphanitic but coarse grains are scattered throughout. Fossils found in boulders of this rock are *Dictyoclostus bassi, D. occidentalis, Meekella* sp., crinoid joints, *Archaeocidaris longispinus, A. ornatus*, a fish tooth, and fenestellid bryozoans. *Dictyoclostus bassi* and *Archaeocidaris* are especially common. This same group of fossils has been found by Wilson[26] in a similar limestone exposed in the Little Harquahala Mountains nearby. Doubtless the "blue limestone" with Permian fossils reported by Stoyanow[27] from gravels in the Bill Baer Hills south of the Harquahala Mountains is derived from the same formation.

The fauna in this limestone indicates a Leonard age for the formation from which it was derived. All of the species are also common in the Beta member of the Kaibab limestone. This fact, together with the lithologic similarity between these limestones, suggests that the Kaibab seaway was continuous across western Arizona. Probably the seaway also extended eastward from the New Water Mountains area into the southeastern part of the state, as pointed out by Stoyanow.[28]

Fossils identical with and representing all of the types listed in the preceding paragraphs, have been collected by the writer in the basal part of the Snyder Hill limestone in the Empire Mountains, and have also been reported from other localities in southern Arizona.

In a second type of limestone that is fairly abundant as a gravel in the conglomerate, additional Permian fossils have been recognized. The rock is strong yellowish brown, aphanitic, and resistant. It weathers a moderate brown. Fossils collected from it include *Composita* sp., *Dictyoclostus* sp., crinoids, and *Archaeocideris* sp. None of these is sufficiently distinctive to make close correlation possible, but the yellowish rock suggests certain beds in the Toroweap formation of northern Arizona and also some in the uppermost member of the Kaibab.

The Permian (?) quartzites are characterized by thin bedding ($\frac{1}{4}$–$\frac{3}{4}$ inch thick), even grain, and flat surfaces. Some large blocks show cross-lamination. Color varies from light gray to very pale red and on weathered surfaces from very pale to weak brown except where coated with a black varnish. Beds of similar quartzite occur beneath fossiliferous Permian limestone strata in the Little Harquahala Mountains 40 miles east. Likewise the Permian (?) quartzites of the New Water Mountains closely resemble strata that appear under the Snyder Hill limestone and above the gypsum and lower limestone beds in the Empire Mountains and elsewhere in southern Arizona.

[26] Personal communication.

[27] A. A. Stoyanow, *op. cit.*, p. 1278.

[28] *Ibid.*

CONCLUSIONS REGARDING PALEOZOIC SEAWAYS

Lithology and fossils of the gravels forming the Cretaceous (?) conglomerates of the New Water Mountains indicate that this part of west-central Arizona was covered by marine waters during parts of Middle Cambrian, Late Devonian, Early Mississippian, Middle Permian, and possibly Late Pennsylvanian time. All of these seaways are believed to have extended into the western Grand Canyon region on the north. The Devonian, Mississippian, and Permian seaways may also have connected with those of corresponding age in southern and southeastern Arizona.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 293-307, 5 FIGS.

CAMBRIAN AND ORDOVICIAN ROCKS IN RECENT WELLS IN SOUTHEASTERN MICHIGAN[1]

GEORGE V. COHEE[2]
Ann Arbor, Michigan

ABSTRACT

All of the wells drilled to pre-Cambrian rocks in the Southern Peninsula of Michigan are located in five counties in the southeastern part of the state bordering the province of Ontario, Canada. The depth to pre-Cambrian in this area ranges from 3,300 feet in Lenawee County to 6,400 feet in Washtenaw County.

The thickness of Middle Ordovician rocks penetrated in these wells varies from 660 feet in Lenawee County to 965 feet in St. Clair County and Upper Ordovician rocks from 585 feet in Washtenaw County to 750 feet in Lenawee County. Lower Ordovician rocks have not been found east of Livingston County. A well drilled on the Howell anticline, near the center of Livingston County, drilled 40 feet of St. Peter sandstone and was abandoned without penetrating the entire thickness of the sandstone. Small areas of commercial oil production occurring in the upper part of the dolomitized Trenton limestone of Middle Ordovician age have been found in Lenawee, Monroe, and Wayne counties, and oil is produced from Middle Orodvician rocks in Kent County, southwestern Ontario.

Rocks of Upper Cambrian age underlie Middle Ordovician rocks and rest on pre-Cambrian rocks in a large part of southeastern Michigan. The thickness of Cambrian rocks varies from 1,160 feet in Washtenaw County to 140 feet in St. Clair County. This variation in thickness is due to the unconformity at the base of Middle Ordovician rocks which was brought about by uplift and erosion at the close of Lower Ordovician time. Cambrian rocks are missing in parts of Kent, Lambton, and other counties in southwestern Ontario, and in these places Middle Ordovician rocks overlie pre-Cambrian rocks. Showings of gas have been reported from the upper part of the Mount Simon sandstone, of Upper Cambrian age, in some of the wells in southeastern Michigan and showings of oil and gas have been found in Cambrian rocks in some wells in parts of southwestern Ontario where these rocks are present.

INTRODUCTION

A study of various stratigraphic problems in the Michigan basin was begun in October, 1943, by the Geological Survey, United States Department of the Interior, in cooperation with the Geological Survey Division, Department of Conservation, Lansing, Michigan, and the Department of Geology, University of Michigan, Ann Arbor, Michigan, as part of its program of oil and gas investigations. A general interest in the oil and gas possibilities, extent, thickness, and lithologic character of the older Paleozoic strata in the Michigan basin gave impetus to regional studies of these rocks in the basin and adjoining areas.

The results of some of the studies have been published by the United States Geological Survey as Preliminary Charts 4, 9, and 11 and Maps 11, 17, 28, 38, and 40 of the Oil and Gas Investigations series. Other regional studies in the Michigan basin are being continued.

The writer is indebted to members of the Michigan, Illinois, Wisconsin, Indiana and Ohio geological surveys, the Geological Survey of Canada and the Department of Geology, University of Michigan, for drill cuttings, well records

[1] Read by title before the Association at Chicago, April 2-4, 1946. Published with the permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, June 14, 1946.

[2] Geologist, Geological Survey, United States Department of the Interior.

and other helpful assistance in the studies. K. K. Landes, chairman of the Department of Geology, University of Michigan, Ann Arbor, George D. Lindberg, Sun Oil Company, Toledo, Ohio, George T. Thomas and R. G. Kurtz, The Ohio Oil Company, Findlay, Ohio, Anthony Folger, consulting geologist, Wichita, Kansas, Jack Hirsch, The Texas Company, Mattoon, Illinois, B. R. MacKay, Geological

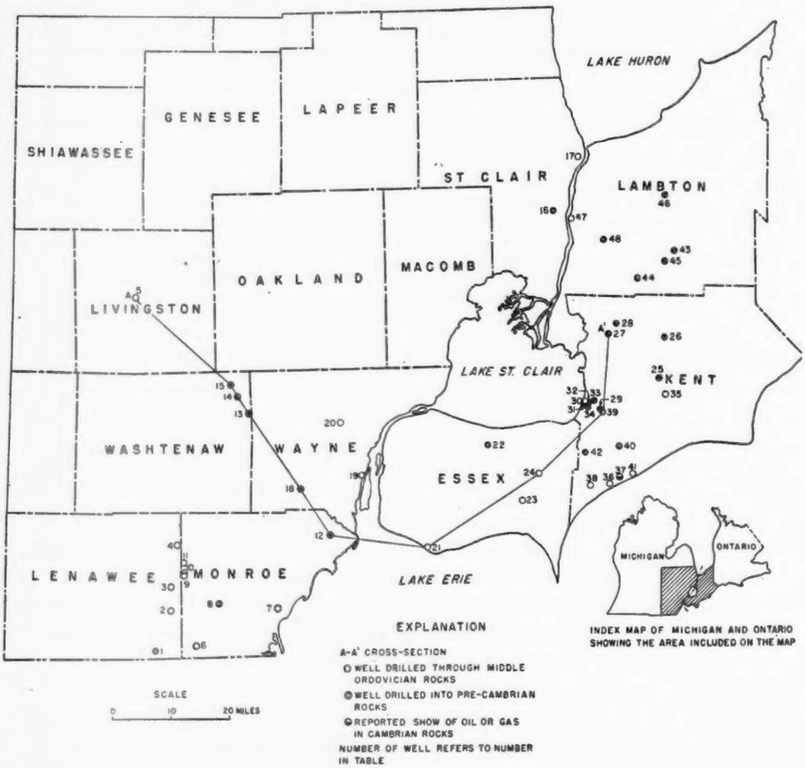


FIG. 1.—Map showing locations of wells drilled through Middle Ordovician rocks and wells drilled to pre-Cambrian rocks.

Survey of Canada, Ottawa, Ontario, and Charles S. Evans, Union Gas Company, Chatham, Ontario, have furnished records and data used in the study and have generously contributed helpful suggestions and criticisms during the course of the study. Criticism of the manuscript by K. K. Landes, University of Michigan, Rex P. Grant and Helen M. Martin, Michigan Geological Survey Division, and H. D. Miser, United States Geological Survey, is greatly appreciated.

WELLS DRILLED TO PRE-CAMBRIAN ROCKS

Prior to 1944 the Hurst well No. 1, drilled in St. Clair County, Michigan, was the only well in the Southern Peninsula of Michigan that had penetrated the full sedimentary section overlying pre-Cambrian rocks. During 1944 and 1945, 6 wells were drilled to pre-Cambrian in southeastern Michigan. The depth to these rocks

TABLE I

WELLS WHICH PENETRATED ENTIRE THICKNESS OF ORDOVICIAN ROCKS IN SOUTHEASTERN MICHIGAN

County, Well, and Number of Well on Map	*Location*			*Surface Elevation of Well*	*Thickness of Upper Ordovician Rocks*	*Thickness of Middle Ordovician Rocks*	*Thickness of Cambrian Rocks*	*Depth to Top of Pre-Cambrian Rocks*	*Total Depth of Well*
	Section	*Township*	*Range*						
LENAWEE COUNTY									
1. Eckert-Taylor 1	32	8 S	5 E	715	709	711	959	3,865	3,900
2. Le Blanc-Fick 1	26	7 S	5 E	688	744	751	[2]	[3]	3,128
3. La Du-Long 2	2	7 S	5 E	708	693	819	[2]	[3]	3,297
4. Socony Vacuum-Downing Est. 1	36	5 S	5 E	698	657	658	[2]	[3]	3,435
LIVINGSTON COUNTY									
5. Duck Lake Oil Co.-McPherson 1	35	3 N	4 E	914	682	903	[2]	[3]	5,958
MONROE COUNTY									
6. Sun-Clampitt 1	28	8 S	6 E	690	701	777	[2]	[3]	2,512
7. Bengood-Saul 1	26	7 S	8 E	595	[1]	850	[2]	[3]	2,516
8. Becko-Sancrant 1	19	7 S	7 E	669	712	802	875	3,625	4,017
9. Vanco-Montry 5	30	6 S	6 E	677	661	717	[2]	[3]	2,874
10. Consolidated-Bragg B 2	30	6 S	6 E	677	682	729	[2]	[3]	3,250
11. Morris-Lidster 1	18	6 S	6 E	707	643	709	[2]	[3]	3,160
12. Sturman-Chapman 1	29	5 S	10 E	597	624	884	486	3,370	3,376
WASHTENAW COUNTY									
13. Colvin Meinzinger 1	12	2 S	7 E	819	593	898	974	5,670	5,692
14. Colvin-Roddenberry 1	27	1 S	7 E	886	584	915	1,051	6,070	6,085
15. Colvin-Ross 1	16	1 S	7 E	915	608	892	1,162	6,372	6,410
ST. CLAIR COUNTY									
16. St. Clair Oil and Gas Corp.—Hurst 1	26	5 N	16 E	620	610	965	140	4,370	4,770
17. Mueller Brass Co.—Van Antwerp 1	9	6 N	17 E	609	650	945	[2]	[3]	4,948
WAYNE COUNTY									
18. Colvin-Theison 1	16	4 S	9 E	625		909	646	4,000	4,050
19. Pennsylvania Salt Mfg. Co.—Well 14	4	4 S	11 E	600	594	846	[2]	[3]	3,368
20. H. R. Ford Well	22	2 S	10 E	612	585	875	[2]	[3]	4,050

[1] Information could not be determined from data available.
[2] Full thickness of Cambrian rocks not penetrated in well.
[3] Well did not reach pre-Cambrian rocks.

ranged from 3,300 feet in Lenawee County to 6,400 feet in Washtenaw County (Table I). The depth to pre-Cambrian rocks increases considerably northwestward from Washtenaw County toward the center of the Michigan basin in southeastern Clare County and southwestern Gladwin County, where it is estimated that approximately 14,000 feet of sediments overlie pre-Cambrian rocks.

A number of wells have been drilled to pre-Cambrian rocks in southwestern Ontario. The depth to pre-Cambrian in some of the wells in that area ranges from 3,500 to 4,200 feet (Table II).

TABLE II

WELLS WHICH PENETRATED ENTIRE THICKNESS OF ORDOVICIAN ROCKS IN ESSEX, KENT, AND LAMBTON COUNTIES, ONTARIO

County, Well and Number of Well on Map	Lot	Concession	Township	Surface Elevation of Well	Thickness of Upper Ordovician Rocks	Thickness of Middle Ordovician Rocks	Thickness of Cambrian Rocks	Depth to Top of Pre-Cambrian Rocks	Total Depth of Well
ESSEX COUNTY									
21. Southern Ontario Gas Co.—Cornwell 1	78	1 Front	Colchester South	593	655	860	[2]	[3]	2,905
22. Jasperson—Girard 1	14	2	Maidstone	602	[1]	853	0	3,496	3,516
23. Imperial Oil Co.—Gulliver	1	7	Meresa	641	716	839	[2]	[3]	3,360
24. E. Coste & Co.—Keck	5	10	Tilbury West	610	734	830	[2]	[3]	3,423
KENT COUNTY									
25. E. P. Rowe—Conliffe 1	6	1	Chatham	598	795	900	22	3,802	3,812
26. Ogletree—Northcutt 2	19	6	Chatham	604	[1]	[1]	[1]	[1]	5,400
27. Union Gas Co.—W. and E. Harper	2	14	Chatham	584	695	936	0	3,696	3,700
28. Union Gas Co.—McCollum 1	6	14	Chatham	587	[1]	948	0	3,715	3,725
29. Union Gas Co.—Duplette	1	2	Dover West	574	785	790	0	3,725	3,774
30. Union Gas Co.—Dover 18	4	4	Dover West	576	727	880	[2]	[3]	3,728
31. Union Gas Co.—Dover 19	3	3	Dover West	577	[1]	882	25	3,765	3,774
32. Union Gas Co.—Dover 21	2	3	Dover West	577	[1]	880	30	3,695	3,700
33. Union Gas Co.—Dover 2	1	3	Dover West	575	733	985	10	3,765	3,770
34. Union Gas Co.—Myers Estate	3	3	Dover West	577	700	880	30	3,765	3,775
35. Union Gas Co.—H. English	2	4	Harwich	595	826	901	[2]	[3]	3,789
36. Erie Petroleum Co.—Dawson 1	194	Talbot Road N.	Tomney	631	830	846	[2]	[3]	3,669
37. Dominion Gas Co.—Shanks	184	Talbot Road N.	Romney	633	847	860	[2]	[3]	3,659
38. E. Coste & Co. 3	19	3	Romney	623	790	830	[2]	[3]	3,528
39. Union Gas Co.—Dover 6	1	2	Tilbury East	578	875	880	35	3,735	3,750
40. Union Gas Co.—Mancell	10	Middle Road N.	Tilbury East	610	798	882	42	3,682	3,682
41. Union Gas Co.—Truckenbrod	174	Talbot Road N.	Tilbury East	636	860	914	[2]	[3]	3,775
42. Southern Ontario Gas Co.—Mallott 6	19	7	Tilbury East	595	[1]	885	[1]	[1]	3,588
LAMBTON COUNTY									
43. E. Coste & Co. 4	30	9	Dawn	665	750	920	20	3,900	3,920
44. Union Gas Co.—Chikds	19	1	Dawn	626	698	937	5	3,855	3,869
45. Union Gas Co.—Mackie 1	26	6	Dawn	656	[1]	940	40	3,900	3,939
46. MacIntosh Oil and Mas Co.—Fee 1	14	10	Enniskillen	627	676	961	17	4,100	4,124
47. Western Salt Company 3	24	W. pt. Front	Moore	600	620	970	[2]	[3]	4,430
48. Sarnia Gas Co.—Haywood 1	16	1	Moore	620	[1]	957	4	4,176	4,180

Note: Refer to footnotes of Table I.

DRILLING CONDITIONS

All of the wells were drilled by cable tools with little difficulty in drilling through the sediments which, in southeastern Michigan, include Mississippian sandstone and shale; Devonian shale, limestone, dolomite, and sandstone; Silurian dolomite with salt, shale and shaly dolomite; Ordovician shale and limestone; and Cambrian dolomite and sandstone. Five strings of casing were used in drilling the Meinzinger well, in Sec. 12, T. 2 S., R. 7 E., Washtenaw County, to pre-Cambrian granite. Sixteen-inch casing was set at 199 feet, 13-inch at 812 feet, 10-inch at 1,560 feet, 8-inch at 4,064 feet, and 6-inch at 5,195 feet. The hole was reamed below 5,195 feet and the 6-inch casing reset at 5,248 feet and again at 5,554 feet.

Water zones in the well were at the following depths: Berea sandstone from

245 to 250 feet, Dundee limestone from 870 to 878 feet, Detroit River formation from 931 to 948 feet, Salina formation from 1,607 to 1,617 feet, base of the Black River limestone from 4,744 feet to 4,758 feet, Franconia sandstone from 5,086 to 5,096 feet, Eau Claire sandstone from 5,204 to 5,208 feet and from 5,233 to 5,244 feet, and Mount Simon sandstone from 5,530 to 5,538 feet.

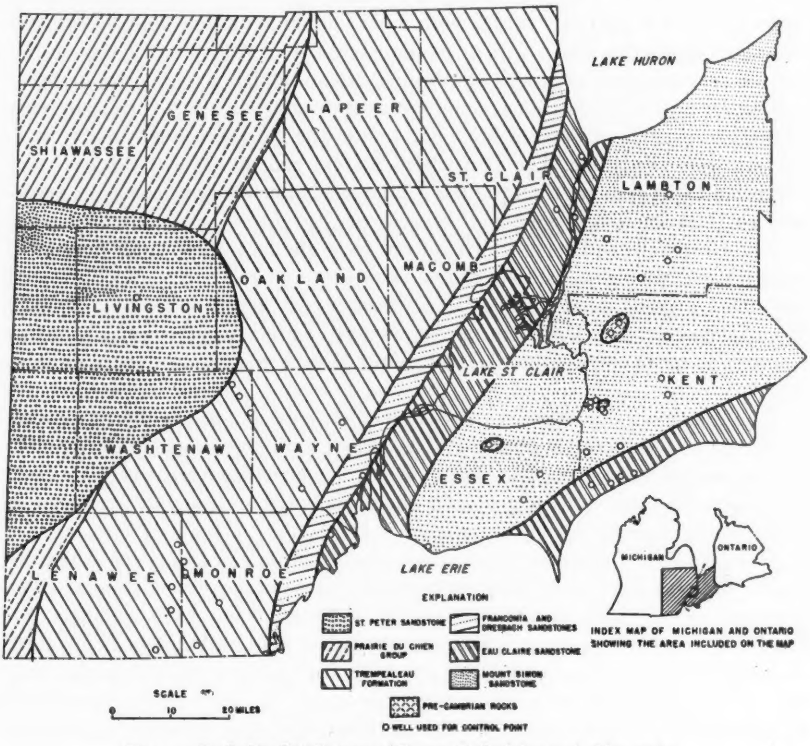


FIG. 2.—Probable distribution of Lower Ordovician and older rocks beneath rocks of Middle Ordovician age.

LITHOLOGY

Upper Cambrian strata rest on pre-Cambrian rocks in southeastern Michigan and southwestern Ontario and are overlain by Middle Ordovician rocks except in Livingston and parts of adjacent counties where Lower Ordovician rocks are present (Fig. 2). In ascending order the Upper Cambrian formations are: Mount Simon sandstone, Eau Claire sandstone, Dresbach sandstone, Franconia sandstone and Trempealeau formation.

The Mount Simon sandstone consists of fine to medium, angular to rounded

quartz grains. Discontinuous thin beds of sandy dolomite occur in various places in the sandstone. Most of the lower part of the sandstone is pink or reddish brown. The greatest thickness of the Mount Simon penetrated by wells in southeastern Michigan is 310 feet.

The Eau Claire sandstone in southeastern Michigan consists of dolomite and dolomitic sandstone. The upper part is glauconitic, pink, purple, brown and gray dolomite which is generally sandy, with minor amounts of gray shale. The lower part is dolomitic sandstone with some glauconite. It is difficult to establish the contact between the Eau Claire and Mount Simon sandstones because the basal part of the Eau Claire becomes much more sandy westward across southeastern Michigan. In parts of western Michigan and in the Northern Peninsula it is almost entirely sandstone. The Eau Claire is from 200 to 260 feet thick. Upper Cambrian rocks younger than the Eau Claire sandstone are not present in southwestern Ontario.

The Dresbach sandstone, which is from 60 to 100 feet thick where present in southeastern Michigan, consists of fine to medium, angular to rounded, frosted and pitted quartz grains. In some places its lower part contains thin beds of white to buff dolomite. The Dresbach sandstone and younger Upper Cambrian rocks are not present in parts of St. Clair, Macomb, Wayne and Monroe counties (Fig. 2).

The Franconia sandstone is a fine- to medium-grained, glauconitic, dolomitic sandstone and glauconitic dolomite. The quartz grains are angular to rounded, frosted, and pitted, and suggest that they may be in part from reworked Dresbach sandstone. The sandstone is generally about 10 feet thick where it is present in southeastern Michigan.

Overlying the Franconia sandstone is the Trempealeau formation which includes the youngest Cambrian rocks found in southeastern Michigan. The Trempealeau in this area includes the St. Lawrence and Lodi members. St. Lawrence member, which is approximately 160 feet thick in Washtenaw County, consists of brown and gray to dark gray dolomite and dark gray dolomitic shale. The lower part is generally sandy and glauconitic. The Lodi member, which is approximately 370 feet thick where the greatest thickness is recorded, is generally white to buff dolomite and may be glauconitic and sandy in part. Some of the dolomite is, however, gray to dark gray, purple, and argillaceous. The purple dolomite grades laterally into white to buff dolomite within a distance of about 6 miles.

The only Lower Ordovician formation penetrated by the drill in southeastern Michigan is the St. Peter sandstone, which was found in the McPherson well drilled on the Howell anticline in Livingston County. The well was abandoned after 40 feet of white sandstone with medium to coarse well rounded sand grains had been drilled. Rocks of the Prairie du Chien group, where penetrated by the drill in southwestern Michigan and northern Indiana, consist of buff to light brown dolomite, cherty in places. Much of the chert is oölitic.

Middle Ordovician rocks in southeastern Michigan are the Trenton and Black River limestones. These rocks consist of brown and gray limestone with minor amounts of argillaceous limestone, shale and dolomite. The Trenton limestone varies from approximately 300 to 500 feet thick in southeastern Michigan and from 350 to 450 feet thick in southwestern Ontario. The Black River limestone varies from 400 to 500 feet in southeastern Michigan and is from 450 to 500 feet thick in southwestern Ontario. Over much of the area a few feet of dolomite may be found in some wells at the top of the Trenton limestone and at the base of the Black River limestone. However, in some areas affected by structural deformation a large part of the Trenton and Black River sequence is dolomite. The basal part of the Trenton limestone in southwestern Ontario consists of dark gray to black shale and shaly limestone, generally 20 feet thick. In southeastern Michigan the basal part is argillaceous limestone with some dark gray shale. The uppermost beds here included in the Black River limestone are believed by Kay[3] to be of Rockland (Trenton) age.

In some places in southeastern Michigan a unit of dolomitic sandstone and brown sandy dolomite is found at the base of Middle Ordovician rocks. This unit corresponds in stratigraphic position with the Glenwood shale of Iowa, Wisconsin, and Illinois, although it may not be the exact time equivalent of the Glenwood farther west.[4] The lithologic character of the rocks of this unit, which are the first deposits of Black River time, depends on the source of the material and the kinds of rock upon which the Black River sea transgressed. In Monroe County, near the subsurface contact of the Upper Cambrian Dresbach sandstone and Middle Ordovician rocks, the Glenwood consists of sandstone and dolomite (well No. 12, Fig. 4); in Livingston County, where the Glenwood overlies the St. Peter sandstone, it is largely sandstone with some dolomite (well No. 5, Fig. 4). In parts of northwestern Ohio, the Glenwood rocks consist of green and gray shale, sandy in places.

Upper Ordovician rocks in southeastern Michigan and southwestern Ontario consist of the Utica, Lorraine, and Queenston shales in ascending order.

The Utica shale in southeastern Michigan is from 150 to 200 feet thick. In Lenawee, Monroe, and Wayne counties, Michigan, it is very dark gray to black and non-calcareous, but northward the shale becomes lighter-colored and in part calcareous so that in the drill cuttings from Livingston County it is difficult to separate the Utica from the overlying Lorraine shale. The shale in southwestern Ontario is dark gray to black and is slightly calcareous near the top and is from 100 to 200 feet thick.

Lorraine shale consists of gray to dark gray, calcareous shale and thin beds of limestone or dolomite in southeastern Michigan where it is from 290 to 390 feet thick. Numerous thin beds of dolomite are in the shale in Lenawee County. The shale becomes more calcareous toward the north with numerous thin beds of

[3] G. M. Kay, personal communication.

[4] E. P. Dubois, personal communication.

limestone. The lithologic character of the shale, which is represented by the Dundas shale and the overlying Meaford shale,[5] in southwestern Ontario is similar to that of the shale in southeastern Michigan. It is 200 to 350 feet thick in southwestern Ontario.

The Queenston shale, which is from 110 to 200 feet thick in southeastern Michigan, consists of light gray to gray shale, calcareous in part, red shale, and interbedded limestone or dolomite. Approximately 10 feet of red shale is at the base of the Queenston in Lenawee County and only a trace of red shale is in the formation in Livingston County, whereas at least half of the Queenston is red shale in Monroe County. In southwestern Ontario, where the shale is 200 to 300 feet thick, it is largely red shale with minor amounts of gray shale and dolomite or limestone.

A study of the drill cuttings of Cambrian and Ordovician rocks penetrated in a well drilled to pre-Cambrian rocks in Washtenaw County, Michigan, follows.

COLVIN-MEINZINGER WELL NO. 1, NE. ¼, NE. ¼, NW. ¼, SEC. 12, T. 2 S., R. 7 E., WASHTENAW COUNTY, MICHIGAN

Elevation above sea-level 818.7 feet. Drilled in 1945.

	Depth in Feet
Ordovician system	
Upper Ordovician series	
Queenston shale	
Shale, gray and red	3,205–3,223
Shale, gray	–3,237
Shale, gray, calcareous, and limestone, grayish brown	–3,319
Shale, red and gray, calcareous, and some limestone	–3,331
Shale, red, slightly calcareous	–3,358
Lorraine shale	
Shale, gray to greenish gray with layers of grayish brown to brown limestone interbedded with the shale	–3,535
Shale, gray, slightly calcareous, and some limestone	–3,648
Utica shale	
Shale, gray to dark gray	–3,750
Shale, dark gray to black	–3,798
Middle Ordovician series	
Trenton limestone	
Dolomite, brown, finely crystalline to dense	–3,802
Limestone, brown to buff, dense, crystalline, some brown dolomite	–3,829
Limestone, buff to brown, finely crystalline to dense	–3,843
Limestone, buff, dense	–3,858
Limestone, buff to brown, finely crystalline to dense; a few scattered fossil fragments	–3,943
Limestone, buff, crystalline, dense	–3,959
Limestone, buff to brown, dense, to finely crystalline; a little dark gray, argillaceous limestone	–4,064
Limestone, dark brown; a little buff, finely crystalline to dense limestone; a small amount of dark gray argillaceous limestone	–4,170
Limestone, dark brown to black, crystalline and dense; a little black calcareous shale	–4,235
Black River limestone	
Limestone, buff to brown, dense; a little gray shale	–4,253
Limestone, buff to grayish brown, dense and crystalline	–4,382
Limestone, grayish brown, dense, some gray argillaceous limestone	–4,500

[5] J. F. Caley, "Paleozoic Geology of the Windsor-Sarnia Area, Ontario," *Canada Geol. Survey Mem. 240* (1946), p. 17.

	Depth in Feet
Limestone, dark brown, dense	−4,526
Limestone, dark grayish brown, dense, argillaceous in part	−4,685
Limestone, dark brown, dense, slightly dolomitic	−4,696
Cambrian system	
Upper Cambrian series	
Trempealeau formation	
Lodi member	
Dolomite, buff, finely crystalline to dense, glauconitic and pyritic	−4,730
Dolomite, buff and dark brown, finely crystalline and dense; trace of chert, slightly sandy	−4,761
Dolomite, dark brown, dense	−4,767
Dolomite, buff, finely crystalline to dense, glauconitic and sandy in part	−4,867
Dolomite, gray, finely crystalline to dense, slightly pyritic and argillaceous	−4,918
Dolomite, tan, finely crystalline to dense	−5,935
Dolomite, grayish brown, finely crystalline to dense	−4,953
St. Lawrence member	
Dolomite, gray to dark gray, dense, argillaceous, glauconitic, pyritic, and sandy in part	−4,981
Dolomite, light brown, dense to crystalline	−4,985
Dolomite, gray to dark gray, buff and brown, finely crystalline to dense, some dark gray shale, pyrite and glauconite	−5,059
Dolomite, grayish brown, finely crystalline, glauconitic; some glauconitic, micaceous sandstone and dark gray, micaceous shale	−5,074
Franconia sandstone	
Sandstone, gray, fine to very fine-grained, glauconitic, and dolomite gray, dense, glauconitic	−5,086
Dresbach sandstone	
Sandstone, pink, fine-grained, angular, friable	−5,098
Sandstone, tan, very fine, friable	−5,107
Sandstone, light rusty brown, fine to very fine-grained, friable	−5,135
Sandstone, light pink, very fine-grained, friable	−5,164
Sandstone, buff, very fine-grained, friable	−5,175
Eau Claire sandstone	
Dolomite, light gray to gray, crystalline, glauconitic, sandy	−5,233
Sandstone, fine- to medium-grained	−5,248
Sandstone, fine- to medium-grained, dolomitic	−5,291
Sandstone, fine- to medium-grained, slightly dolomitic in part	−5,348
Mount Simon sandstone	
Sandstone, white, friable, fine-grained	−5,367
Sandstone, white, fine- to medium-grained, friable	−5,595
Sandstone, pink, light brown, fine-, medium-, and coarse-grained, friable	−5,631
Sandstone, pink to light brown, fine-, medium-, and coarse-grained, friable, some fragments of granite	−5,670
Pre-Cambrian (granite)	−5,692 Total Depth

Sample study by Lloyd B. Underwood and George V. Cohee.

STRUCTURE

The area included in this study is on the southeast margin of the Michigan basin and along the Findlay arch[6] which extends northward from the Lima-Indiana oil field in northwestern Ohio into Monroe County, Michigan, and northeastward into Essex and Kent counties, Ontario. Near the center of Kent County a depression, shown by contours on the top of the Trenton limestone (Fig. 3),

[6] Ekblaw favors the use of the term Findlay arch for the northeast branch of the Cincinnati arch and the restriction of the name Cincinnati arch to the main structure south of the bifurcation. G. E. Ekblaw, "Kankakee Arch in Illinois," *Bull. Geol. Soc. America*, Vol. 49 (1938), p. 1428.

has been called the Chatham sag.[7] This depression is reflected in the pre-Cambrian surface and in the overlying Paleozoic sediments. The increased thickness of certain Paleozoic rocks in the area of the Chatham sag indicates that it was a structural depression at several times during the Paleozoic era, and probably served as a connection between the Michigan and Appalachian basins at these

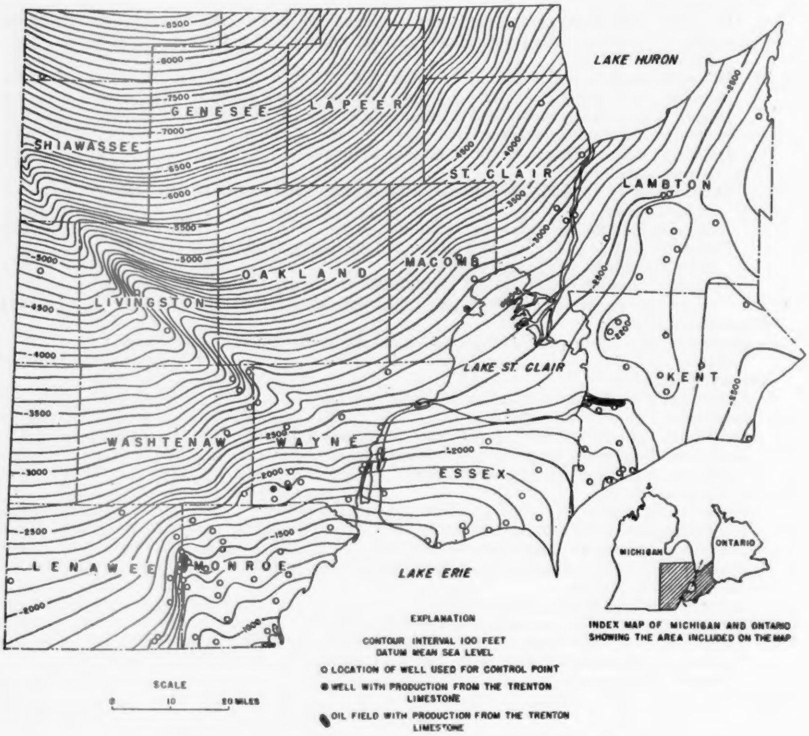


FIG. 3.—Structure contours on top of Trenton limestone.

times. Northeastward from the Chatham sag the Trenton limestone rises along an arch throughout southwestern Ontario which has been referred to as the Algonquin axis.[8]

Areas of closure on the top of the Trenton limestone are noted in northeastern Kent County and southern Lambton County, Ontario. Undoubtedly additional structural data would indicate other closed structures in the area of the map.

[7] G. M. Kay, "Development of the Northern Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1621.

[8] G. M. Kay, *op. cit.*, p. 1604.

In southern Michigan the Howell anticline is the most important structure shown by the contour map on the Trenton limestone. This structure, which has been described in detail by Newcombe[9] begins in Wayne County and extends through Oakland, Livingston, and Shiawassee counties. Its greatest structural relief is near the center of Livingston County.

Contours on the Trenton limestone in western Monroe and eastern Lenawee counties indicate a sharp west dip off the west edge of the northern extension of the Findlay arch. This has been referred to by some workers in surface stratigraphy as the Lucas-Monroe counties monocline.[10] Indications of faulting along this structure have been found, particularly its southward extension into Lucas County, Ohio. The fault is apparently connected with the Bowling Green fault, one of the important structural features in northwestern Ohio, which extends north and south through the oil-producing areas in the vicinity of Bowling Green, Cygnet, and Findlay.[11] Wells drilled along the fault near Bowling Green show a drop in the top of the Trenton limestone of more than 200 feet between well locations. The downthrown side of the fault is on the west.

Other structural irregularities on the top of the Trenton limestone, such as those indicated in Monroe County, will undoubtedly be found in other parts of southeastern Michigan when more structural data are available.

Thinning of the Black River limestone in the Deerfield pool area (Fig. 5) suggests some movement at the close of Black River time at least in localized areas.

UNCONFORMITY AT BASE OF MIDDLE ORDOVICIAN ROCKS

At the close of Lower Ordovician time the Findlay arch and the Algonquin axis were elevated, and Cambrian and Lower Ordovician rocks were stripped from these structures by subsequent erosion. A study of well records and drill cuttings from northeastern Illinois through northeastern Indiana to northwestern Ohio and northward to southwestern Ontario shows the truncation of Lower Ordovician and Upper Cambrian rocks along the Findlay arch. Figure 4 shows the truncation of Upper Cambrian rocks from southeastern Michigan to southwestern Ontario. In parts of southwestern Ontario, Middle Ordovician rocks overlie pre-Cambrian rocks (Fig. 2). Of the 4,000 feet of Cambrian and Lower Ordovician rocks in northeastern Illinois approximately 2,300 feet is the upper Cambrian Mount Simon sandstone. The Mount Simon sandstone thins eastward, but the other beds maintain a fairly uniform thickness except where they are

[9] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38,* Geol. Ser. 32 (1933), p. 205.

[10] J. Ernest Carman, "Resume of the Geology of Lucas County, Ohio," *Proc. Ohio Acad. Sci.*, Vol. 8, Pt. 4 (1928), p. 173.
G. M. Ehlers, "A Study of the Lucas County, Ohio-Monroe County, Michigan Monocline and Stratigraphy of Northwestern Ohio and Southeastern Michigan," *Michigan Acad. Sci. Guide to 5th Annual Field Trip* (1935).

[11] Wilbur Stout, "Dolomite and Limestone of Western Ohio," *Ohio Geol. Survey, Bull. 42,* 4th Ser. (1941), p. 17.

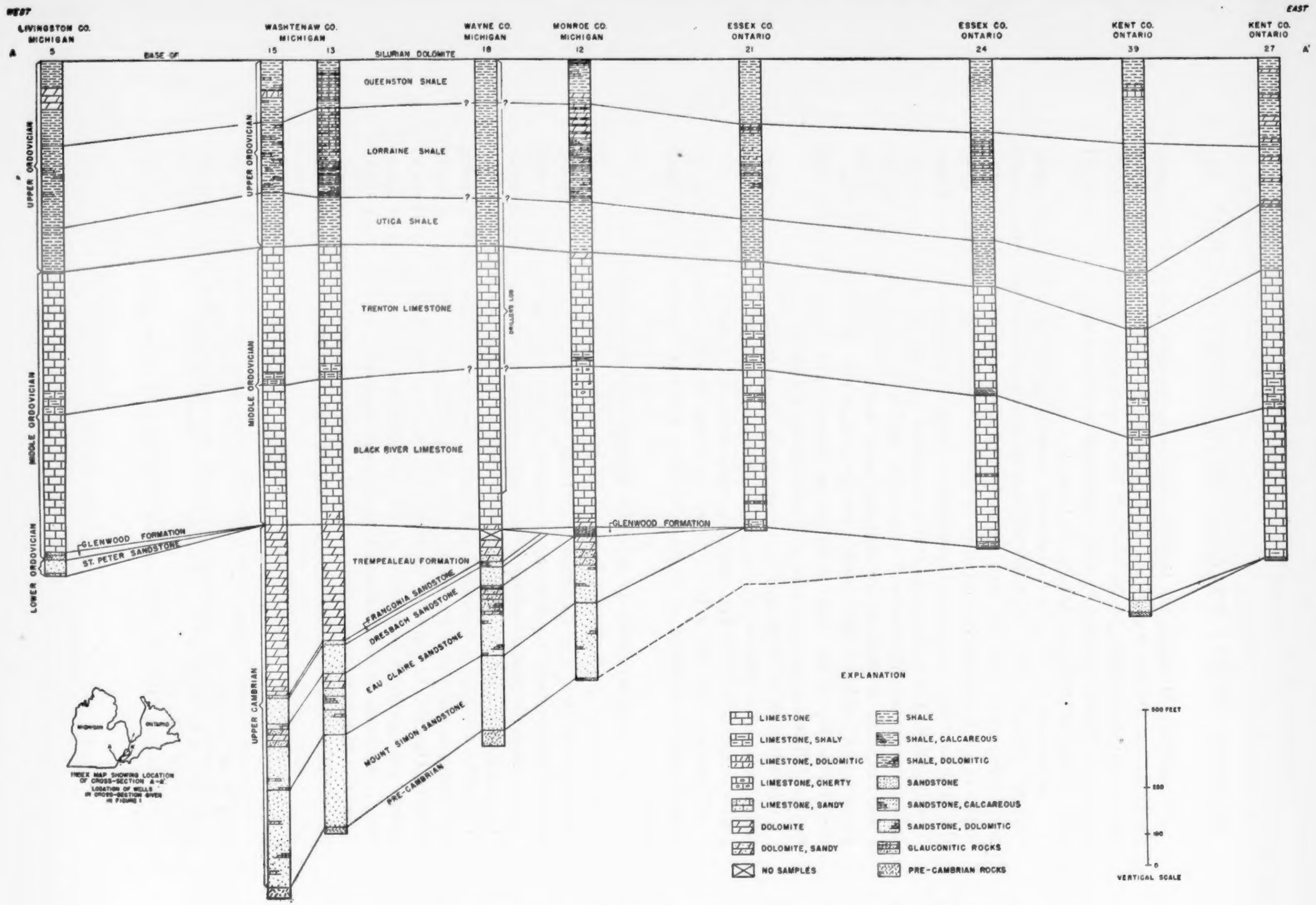


FIG. 4.—Graphic sections of Cambrian and Ordovician rocks in southeastern Michigan and southwestern Ontario.

truncated. The thinning of the Mount Simon sandstone to the east suggests some elevation of the Findlay arch during Mount Simon time.

The irregular distribution of the St. Peter sandstone in southwestern Michigan, indicated by well records and drill cuttings, suggests the possible overlap of the sandstone on rocks older than Lower Ordovician in southeastern Michigan as shown in Figure 2.

A thickness map of the St. Peter sandstone in eastern Wisconsin prepared by Thwaites[12] shows that the sandstone is absent in some areas and approximately 300 feet thick elsewhere. Similar local variations in thickness in northeastern Illinois are shown both on a thickness map prepared by Lamar[13] and through recent work by Dubois.[14] The St. Peter sandstone unconformably overlies Lower Ordovician and Cambrian strata in parts of northern Illinois and Wisconsin and unconformably overlies Lower Ordovician beds in northwestern Indiana and southwestern Michigan.

Although no well has penetrated rocks of the Prairie du Chien group of Lower Ordovician age in southeastern Michigan, their presence in that part of the state is inferred from the fact that several hundred feet of these rocks are in northeastern Indiana at the southern margin of the Michigan basin and in southwestern Michigan. These rocks were eroded from the elevated areas at the close of Lower Ordovician time. Powers[15] states that the Prairie du Chien rocks in northern Illinois and Wisconsin were evidently eroded to a surface of high relief and completely removed in a large area.

PRODUCTION, OCCURRENCE, AND POSSIBILITIES OF OIL AND GAS

The Trenton limestone is the only formation of the Cambrian and Ordovician sequence of rocks in the area included in the study from which commercial oil and gas production has been obtained.

Oil and gas are produced from the Trenton limestone in the Deerfield field, Dundee Township, Monroe County, Michigan, at a depth of 1,050 feet. The field was discovered in 1920 but development was not active until 1929. More than 400,000 barrels of oil have been produced from the 33 successful wells drilled in this field.[16] The initial daily production of the wells ranged from 4 to 800 barrels. Production is from porous zones on the flanks of the anticlinal fold at depths varying from 3 to 120 feet below the top of the Trenton. Other areas of Trenton production in southeastern Michigan are one- and two-well fields in Sumpter and

[12] F. T. Thwaites, personal communication.

[13] J. E. Lamar, "Isopach Map of St. Peter Formation," *Rept. 9th Ann. Field Conf.*, Kansas Geol. Soc. (1935), Fig. 23.

[14] E. P. Dubois, personal communication.

[15] E. H. Powers, "Isopach Map of the Prairie du Chien Group," *Rept. 9th Ann. Field Conf.*, Kansas Geol. Soc. (1935), p. 350.

[16] Geological Survey Division, Michigan Department of Conservation.

Huron townships, Wayne County. A producing well was completed in 1941 in Sec. 22, Sumpter Township, which had an initial production of 12 barrels of oil with water. Production was obtained at depths of 10 to 17 feet and 43 to 74 feet from the top of the Trenton limestone. Two wells were drilled in 1942 in the New Boston field in Sec. 18, Huron Township. The initial production of each well was 10 barrels and the producing zone was reached at a depth of 120 feet in the Trenton.

Oil and gas production has been obtained from the Trenton and Black River

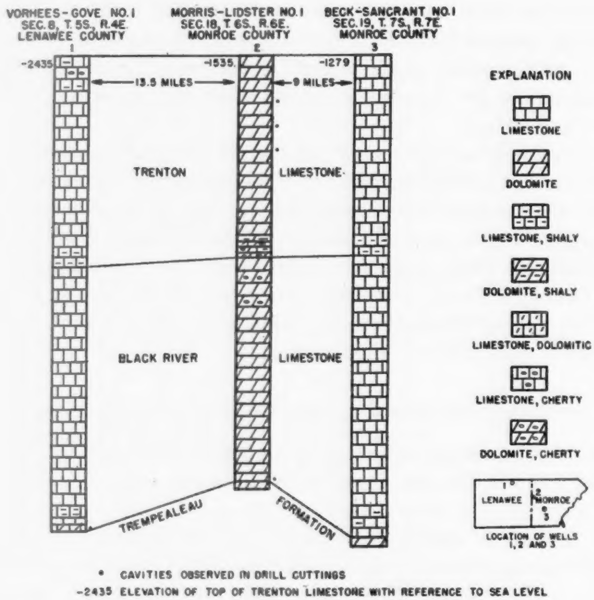


FIG. 5.—Dolomitization of Trenton and Black River limestones in Lenawee and Monroe counties, Michigan.

limestones in the Dover Field, Kent County, which is the most important area of Trenton production in Ontario. The field was discovered in 1917 and has produced more than 9,000,000,000 cubic feet of gas and 200,000 barrels of oil, and recently it had 8 oil wells and 3 gas wells in operation.[17] The field is in a syncline and porosity is believed to be due to faulting.[18] Oil and gas production is obtained at depths of 282 feet and 400 feet below the top of the Trenton.

In an area near the Deerfield pool, Monroe County, the Trenton and Black

[17] C. S. Evans, personal communication.

[18] J. F. Caley, *op. cit.*, p. 86.

River rocks are almost entirely dolomite, whereas a few miles west and east of the anticlinal fold they are almost entirely limestone (Fig. 5). Dolomitization of the limestone along the fold, which may be faulted in part, has developed sufficient porosity in certain zones for the accumulation of oil and gas. These porous zones are found at various depths in the dolomitized limestone. Solution cavities and dolomite crystals were observed in drill cuttings of the dolomitized rocks. A similar condition of dolomitization on structure is in the Trenton and Black River limestones in the Lima-Indiana field.

In the Lima-Indiana field dolomitization occurred throughout great thicknesses of the Trenton and Black River limestones along the Findlay arch, and oil and gas production is confined to the area where the limestone was dolomitized. The dolomite in the producing zone contains irregular areas of porosity as shown by thin sections.[19] Rock fragments from the producing zone blown out of the well at the time of shooting showed honeycomb structure with openings several inches long, and some specimens were porous on one side and dense on the other side. The surface of the cavities indicated that they were caused by solution.

Dolomitization of the limestone in these areas was apparently associated with folding and faulting, and according to Landes[20] solutions migrating upward along fracture zones altered the limestone vertically and horizontally. As the Trenton limestone is a dense limestone with little porosity except where it has been dolomitized, it therefore appears that commercial oil and gas production can be obtained even on anticlines and domes only where dolomitization has taken place. The size of the fields in the Trenton depends on the magnitude of the structures and the extent to which dolomitization of the limestone has taken place. The upper part of the Trenton offers the most promise of commercial oil and gas, but as the Black River strata yield some oil in the Lima-Indiana field, the possibility of testing these rocks in other areas should be considered.

Shows of gas were found in the top of the Mount Simon sandstone in the Voss, Roddenberry, Meinzinger, Theison and Chapman wells in southeastern Michigan (Table I). Although the showings were slight, the operators were sufficiently interested to test these zones by setting casing to shut off the water in the wells. All attempts failed to obtain commercial production of gas.

Commercial oil production has been obtained from Cambrian and Lower Ordovician rocks in parts of Ohio on the east side of the Findlay arch near the contact with the overlying Middle Ordovician rocks, and showings of oil have been found in these rocks in northeastern Indiana and southwestern Ontario. It thus appears that stratigraphic and porosity traps may be present along the strike of the truncated Cambrian and Ordovician beds where they wedge out against the Findlay arch in southeastern Michigan and southwestern Ontario.

[19] J. A. Bownocker, "The Occurrence and Exploitation of Petroleum and Natural Gas in Ohio," *Ohio Geol. Survey Bull. 1*, 4th Ser. (1903), pp. 31–101.

[20] K. K. Landes, "Porosity through Dolomitization," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 3 (March, 1946), p. 317.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 308-317

MODAL ANALYSES OF WELL CORES FROM BASEMENT COMPLEX IN WEST TEXAS[1]

LEROY T. PATTON[2]
Lubbock, Texas

This paper is a continuation of studies of the basement complex of West Texas made possible by cores obtained in deep-well drilling and contains the results of studies of material obtained since publication of a previous paper.[3] The present paper contains the results of studies of cores from 10 wells in 10 different counties of West Texas. That there is one representative from each of the 10 counties is a mere coincidence and should not be taken as an attempt to present representative rocks for each county. The studies were merely made upon material available. For convenience the results are presented in the geographical order of the counties, beginning with the northernmost tier of counties and continuing south.

The modes of the rocks have been computed from mineralogical analyses according to the Rosiwal method. In making measurements of the mineral grains, use was made of an improved Wentworth recording micrometer, which is graduated to read to 0.005 millimeter.

The classifications made in this paper are according to the Johannsen system of quantitative mineralogical classification.[4]

CORE FROM THE TEXAS COMPANY NO. 1, CAPITOL FREEHOLD LAND TRUST, DALLAM COUNTY, TEXAS

This well is located 660 feet from the south and east lines of Section 10, Block 7, Capitol Freehold Land Trust, Dallam County, Texas. It was drilled to the total depth of 6,169 feet. Igneous rock was reported from 6,112 to 6,169 feet. Through the courtesy of W. H. McConnell of The Texas Company, a small sample suitable for the making of thin sections was furnished the writer.

Megascopic.—The rock is fine-grained, reddish color, showing a few small phenocrysts.

Microscopic.—The rock has porphyritic texture, consisting of a groundmass of granophyric aggregate of quartz and feldspar. Some spherulitic forms in addition to the patches of intergrown quartz and feldspar. The phenocrysts consist of quartz, orthoclase, and oligoclase. The rock would, therefore, be classed as a

[1] Manuscript received, June 6, 1946.

[2] Professor of geology, Texas Technological College.

[3] Leroy T. Patton, "Igneous Rocks from Deep Wells in West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 7 (July, 1945), pp. 1028–34.

[4] Albert Johannsen, *A Descriptive Petrography of the Igneous Rocks*, pp. 141–61. University of Chicago Press (1939).

granophyre or if Rosenbusch's classification is followed, a granophyric granite porphyry.

CORE FROM HUMBLE OIL AND REFINING COMPANY'S MATADOR NO. 1-E, OLDHAM COUNTY, TEXAS

This well is located 2,640 feet from the south line and 6,600 feet from the north line of League 329, State Capitol Lands, Oldham County, Texas. Igneous rock encountered at 6,280 feet.

Megascopic.—Rock is medium- to coarse-grained, of a reddish color and showing crystals of reddish feldspar and crystals of quartz.

Microscopic.—Texture is zenomorphic-granular. The section shows crystals of quartz and orthoclase. The orthoclase shows some microperthic intergrowths. The orthoclase is very cloudy from alteration.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Potash Feldspar*
1	3.255 mm.	8.825 mm.
2	13.055	9.995
3	3.100	9.620
4	4.420	8.670
5	3.330	10.145
6	3.775	11.610
7	3.125	6.765
8	3.305	6.010
9	6.400	6.360
10	5.950	6.990
11	8.735	0.000
12	10.635	5.225
13	5.040	8.370
14	4.995	7.110
15	1.530	8.750
Total	80.650	114.445

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	41.4
Potash feldspar	58.5
	99.9

Leucocrates 100 per cent of total components	Class 1
No plagioclase except in perthitic intergrowths	Order 1
Quartz 41.4 per cent of quarfeloids	Families 5–8
Potash feldspar only feldspar except perthitic intergrowths	Family 5
Rock number	115
Rock name	Kalialaskite

CORE FROM PHILLIPS PETROLEUM COMPANY NO. 2, PAN-BERNARD, CARSON COUNTY, TEXAS

This well is located 2,334 feet from the north line and 994 feet from the east line of Section 24, Block 4, I and GN Survey, Carson County, Texas. Through

the courtesy of W. T. Lilly of Amarillo, a sample of a core was furnished the writer for study.

Megascopic.—The rock is phaneritic, medium-grained, showing crystals of feldspar, some of which have a pinkish tinge, quartz, and dark minerals.

Microscopic.—Section shows crystals of quartz, orthoclase, sodaclase, and biotite, which is largely altered to chlorite.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Potash Feldspar*	*Sodaclase*	*Biotite and Chlorite*
1	1.135 mm.	2.995 mm.	1.505 mm.	0.000 mm.
2	0.600	1.180	3.420	1.380
3	0.950	4.565	0.660	2.355
4	1.605	3.770	2.120	1.365
5	2.220	2.465	2.715	1.315
6	1.390	2.840	2.205	1.260
7	1.495	1.415	2.650	2.230
8	1.985	3.420	0.200	2.325
9	2.000	4.305	0.480	0.435
10	3.280	2.405	0.420	0.520
11	0.870	3.695	0.000	0.405
12	1.510	2.445	0.000	1.015
13	0.415	2.360	0.000	0.180
14	0.215	1.960	0.715	0.665
15	0.100	1.495	0.000	0.000
Total	19.770	41.315	17.090	15.450

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	21.1
Potash feldspar	44.1
Sodaclase	18.2
Biotite and chlorite	16.6
	100.0

Leucocrates make up 83.9 per cent of total components................................Class 2
Plagioclase is sodaclase..Order 1
Quartz 25.1 per cent of quarfeloids..Families 5–8
Potash feldspar 72.0 per cent of total feldspar..Family 6
Rock number...216
Rock name...Sodaclase-granite

WELL IN SECTION 29, BLOCK B-2, H. AND G.
SURVEY, CARSON COUNTY, TEXAS

Through the courtesy of Porter Montgomery the writer was furnished a very small piece of rock from a well in this location. It is not now possible to identify the exact well. The piece was just sufficient to make a thin section.

Microscopic.—The texture of the rock is holocrystalline-xenomorphic granular. Crystals of quartz, orthoclase, some microcline, and a small amount of dark constituents consisting mainly of hematite and magnetite. Staining by the hematite gives the section a slightly reddish tint.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Potash Feldspar*	*Dark Constituents*
1	5.510 mm.	5.975 mm.	0.205 mm.
2	4.480	7.110	0.035
3	1.845	7.305	0.460
4	5.990	6.915	0.675
5	5.285	8.025	0.350
6	3.750	7.655	0.275
7	2.860	8.715	0.180
8	7.745	4.430	1.195
9	6.210	7.155	0.005
10	6.110	7.820	0.960
11	5.515	6.810	0.160
12	5.850	4.560	0.150
13	9.260	3.045	0.035
14	5.005	7.310	1.030
15	3.315	7.185	0.170
Total	78.730	100.015	5.885

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	42.6
Potash feldspar	54.1
Dark constituents	3.1
	99.8

Leucocrates 96.7 per cent of the whole........Class 1
No plagioclase........Order 1
Quartz 44.2 per cent of quarfeloids........Families 5–8
Potash feldpar 100 per cent of feldspar........Family 5
Rock number........115
Rock name........Kalialaskite

CORE FROM EL PASO NATURAL GAS COMPANY'S WEST TEXAS MORTGAGE AND LOAN COMPANY NO. 1, BAILEY COUNTY, TEXAS

The El Paso Natural Gas Company's West Texas Mortgage and Loan Company No. 1 is located 694 feet from the south line and 650 feet from the west line of Section 55, Block A, M. B. and B. Survey, Bailey County, Texas. The well was drilled to the total depth of 9,112 feet. Through the courtesy of W. K. Davis of the El Paso Natural Gas Company, the writer was furnished a portion of the core of igneous rock encountered.

Megascopic.—The rock is granular, somewhat dark-colored, showing crystals of feldspar and dark-colored minerals. On polished section grains of magnetite seem to be rather abundant.

Microscopic.—Medium-grained hypautomorphic texture. Rock consists of crystals of labradorite, augite, olivine, serpentine, and a relatively large amount of magnetite. The labradorite shows considerable alteration.

ROSIWAL ANALYSIS

Traverse	*Labradorite*	*Augite*	*Olivine and Serpentine*	*Magnetite*
1	11.490 mm.	0.305 mm.	4.170 mm.	0.230 mm.
2	11.550	0.850	2.840	1.755
3	12.150	1.025	2.450	1.625
4	12.045	1.475	3.135	0.490
5	13.435	1.727	1.650	0.000
6	12.120	1.635	1.675	1.140
7	8.635	4.350	1.615	0.000
8	10.890	0.325	3.660	2.850
9	10.945	0.150	1.910	3.470
10	12.925	0.000	0.695	2.550
11	12.515	0.000	0.620	1.195
12	14.170	0.000	1.545	0.000
13	11.625	2.380	2.620	1.050
14	10.615	1.275	1.410	2.385
15	14.425	2.435	1.095	0.170
Total	179.535	17.932	31.090	18.910

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Labradorite	72.5
Augite	7.2
Olivine and serpentine	12.6
Magnetite	7.6
	99.9

Leucocrates make up 72.5 per cent of total components	Class 2
Plagioclase is labradorite	Order 3
No quartz	Families 9–12
Plagioclase 100 per cent of the feldspars	Family 12
Rock number	2312
Rock name	Gabbro

CORE FROM GEORGE P. LIVERMORE'S KRAUSE NO. 1, FLOYD COUNTY, TEXAS

George P. Livermore's Krause No. 1 is located 660 feet from the south and east lines of Section 29, Block K. T. T. Railroad Company Survey, Floyd County, Texas. It was drilled to the total depth of 7,843 feet. Igneous rock was encountered from 7,834 to 7,843 feet. Through the courtesy of Leonard Latch of the George Livermore Company, the writer was given a sample of the core of the igneous rock for study.

Megascopic.—The rock is medium-grained, somewhat dark-colored, showing crystals of quartz, feldspar, and biotite.

Microscopic.—The texture is hypautomorphic-granular, medium-grained, consisting of crystals of quartz, orthoclase, andesine, biotite, green hornblende, and a few accessory euhedral crystals of sphene and apatite.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Potash Feldspar*	*Andesine*	*Biotite*	*Hornblende*
1	1.745 mm.	4.430 mm.	1.095 mm.	1.860 mm.	1.220 mm.
2	2.335	2.515	2.055	0.510	0.510
3	2.299	1.945	0.930	2.965	0.470
4	1.560	2.155	4.975	0.000	0.315
5	2.185	1.810	5.435	1.230	0.000
6	1.390	1.215	3.945	1.345	0.000
7	1.735	2.560	4.480	1.390	0.720
8	1.465	2.840	3.675	0.610	0.910
9	3.415	2.040	3.015	1.310	0.885
10	0.465	5.020	2.835	1.490	0.480
11	2.495	4.125	4.170	0.335	0.900
12	3.015	3.550	2.375	0.000	0.625
13	1.260	2.035	3.285	0.890	0.300
14	0.090	1.850	7.000	0.115	0.000
15	1.640	3.600	3.470	0.325	0.000
Total	27.094	41.690	52.740	14.375	7.335

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	19.0
Potash feldspar	29.3
Andesine	36.6
Biotite	10.0
Hornblende	5.1
	100.0

Leucocrates make up 85 per cent of the total..Class 2
Plagioclase is andesine..Order 2
Quartz 22.2 per cent of quarfeloids..Families 5–8
Potash feldspar is 44.6 per cent of total feldspars..Family 7
Rock number..227
Rock name..Granodiorite

CORE FROM STANOLIND OIL AND GAS COMPANY'S SLAUGHTER NO. 1, COCHRAN COUNTY, TEXAS

This well is located 440 feet from the north and east lines of Labor 49, League 101, Jeff Davis School Land, Cochran County, Texas. It was drilled to the total depth of 10,840 feet. A core was taken from 10,839 to 10,840 feet. Through the courtesy of D. H. Reno of the Stanolind Oil and Gas Company, the writer was furnished a small piece of the core for study.

Megascopic.—The rock is fine-grained, porphyritic, somewhat reddish or pinkish in color.

Microscopic.—Texture is hypautomorphic granular, porphyritic. The ground mass consists of granular orthoclase. Measurements of crystals of groundmass by means of recording micrometer show distribution of approximately 2,000 per square centimeter. Phenocrysts of orthoclase are scattered through the ground mass. The orthoclase phenocrysts are generally clear but show more or less cloudiness. A smaller percentage of oligoclase crystals also appear as phenocrysts.

A few flakes and small shreds of particles of dark constituents are scattered through the groundmass. The dark constituents consist mainly of biotite, largely altered to chlorite.

The section is cut by a few veins of quartz. The quartz crystals do not appear in the section anywhere except in the veins. The quartz in the veins, therefore, was not taken into consideration in the analysis, as it evidently does not belong to the original rock.

ROSIWAL ANALYSIS

Traverse	*Potash Feldspar*	*Oligoclase*	*Dark Constituents*
1	12.685 mm.	0.685 mm.	1.010 mm.
2	11.125	0.000	0.705
3	12.255	1.025	0.910
4	11.210	0.000	0.410
5	15.890	0.090	0.610
6	14.510	0.025	0.665
7	10.810	2.010	0.910
8	11.050	0.860	0.825
9	10.790	0.000	0.605
10	10.530	0.200	0.090
11	12.435	0.420	1.150
12	11.140	0.000	0.675
13	8.085	0.580	0.385
14	10.170	1.530	0.580
15	8.005	2.100	0.000
Total	170.690	9.525	9.530

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Potash feldspar	90.0
Oligoclase	5.0
Dark constituents	5.0
	100.0

Leucocrates make up 95 per cent of total components	Class 2
Plagioclase is oligoclase	Order 2
No quartz	Families 9–12
Plagioclase is 5.2 of total feldspars	Family 10
Rock number	2210
Rock name	Syenite-porphyry

CORE FROM MAGNOLIA PETROLEUM COMPANY'S L. D. JOHNSTON NO. 1, LUBBOCK COUNTY, TEXAS

The Magnolia Petroleum Company's L. D. Johnston No. 1, located 660 feet from the north and west lines of Section 88, Block C, D. and W. Ry. Co. Survey, Lubbock County, Texas, which was completed in February, 1945, encountered igneous rock at a depth of 10,169 feet. Cores were taken to the total depth of 10,178 feet. Through the courtesy of L. Wayne Ashmore of the Magnolia Petroleum Company, the writer was given a core from 10,175 feet for study.

Megascopic.—The rock is light-colored, medium-grained, consisting of crystals of pinkish feldspar, grains of quartz, and a moderate amount of biotite.

Microscopic.—The texture is hypautomorphic-granular. The minerals are quartz, orthoclase, andesine, green biotite, and some euhedral crystals of apatite occurring as accessory mineral. The quartz contains numerous gas and liquid inclusions arranged in roughly parallel lines. Also such inclusions irregularly arranged. The feldspars are relatively fresh and unaltered.

ROSIWAL ANALYSIS

Traverse	*Quartz*	*Alkali Feldspar*	*Biotite*	*Andesine*	*Magnetite*
1	6.345 mm.	7.225 mm.	0.440 mm.	0.000 mm.	0.105 mm.
2	2.030	9.765	2.900	0.000	
3	3.725	5.745	1.755	4.745	
4	0.015	11.835	0.600	2.650	
5	2.545	13.165	0.940	0.000	
6	4.050	9.315	2.740	1.430	
7	2.380	5.045	1.125	1.262	
8	1.770	12.535	0.150	0.000	
9	1.865	7.465		2.075	
10	3.280	13.899		1.900	
Total	28.005	92.994	10.650	14.062	0.105

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Quartz	18.8
Alkali feldspar	64.5
Biotite	7.2
Andesine	9.4
Magnetite	0.1
	100.0

Leucocrates make up 92.0 per cent of total components....Class 2
Plagioclase is andesine....Order 2
Quartz is 21 per cent of total quarfeloids....Families 5–8
Alkali feldspar 87 per cent of total feldspars....Family 6
Rock number....226P
Rock name....Granite

CORE FROM GEORGE P. LIVERMORE'S BIRD NO. 1, DICKENS COUNTY, TEXAS

The George P. Livermore Bird No. 1 is located 660 feet from north and 1,980 feet from east line of Section 288, Block 1, H. and G. N. Survey, Dickens County, Texas. The well was drilled to the total depth of 8,390 feet with top of igneous rock reported at 8,388 feet. A core was taken from 8,389 to 8,390 feet. Through the courtesy of Leonard Latch, geologist for the George P. Livermore Company, the writer was given a sample of the core for study.

Megascopic.—A coarse-grained light-colored igneous rock. Crystals of pink feldspar, quartz, and biotite.

Microscopic.—Hypautomorphic texture. Crystals of quartz, orthoclase, oligoclase, and biotite. Some of the biotite altered to chlorite. A few crystals of apatite occur as accessory minerals.

ROSIWAL ANALYSIS

Traverse	Quartz	Potash Feldspar	Oligoclase	Biotite and Chlorite
1	8.925 mm.	3.650 mm.	1.135 mm.	1.450 mm.
2	5.835	2.145	4.450	0.000
3	9.840	2.140	4.445	0.000
4	9.230	4.190	3.430	0.520
5	6.450	10.500	0.290	0.310
6	5.255	4.345	6.605	1.060
7	2.055	6.030	9.195	1.320
8	0.000	7.700	10.410	0.415
9	1.540	5.195	10.350	0.495
10	3.595	6.740	5.450	3.465
11	2.540	2.300	11.115	1.020
12	1.810	8.950	4.735	1.725
13	2.385	4.855	10.150	0.745
14	1.625	13.590	0.000	0.000
15	2.010	10.700	0.510	0.000
Total	63.095	93.030	82.270	12.525

PERCENTAGE COMPOSITION

Minerals	Percentage
Quartz	25.1
Potash feldspar	37.0
Oligoclase	32.8
Biotite and chlorite	5.0
	99.9

Leucocrates make up 94.9 per cent of total components	Class 2
Plagioclase is oligoclase	Order 2
Quartz 28 per cent of quarfeloids	Families 5–8
Potash feldspar 52 per cent of total feldspar	Family 6
Rock number	226
Rock name	Granite

CORE FROM ANDERSON-PRICHARD OIL CORPORATION'S NO. 2, MASTERSON, PECOS COUNTY, TEXAS

This well is located 660 feet from the northeast and northwest lines of Section 104, H. and G. N. Ry. Company Survey, northern Pecos County, Texas. It was drilled to the depth of 4,650 feet. Through the courtesy of G. C. Clark of the Stanolind Oil and Gas Company, the writer was furnished a sample of the core for study.

Megascopic.—A piece about $\frac{1}{4}\times\frac{1}{4}\times\frac{1}{4}$ inch was available for study. It is a dark-colored, medium-grained igneous rock showing crystals of plagioclase feldspar and dark minerals. This piece caused a slight disturbance of the magnetic needle of a Brunton compass when held very close to the needle.

Microscopic.—The section contains crystals of labradorite, hypersthene, a relatively large amount of flakes of magnetite, and considerable chlorite (antigorite).

ROSIWAL ANALYSIS

Traverse	*Labradorite*	*Hypersthene*	*Magnetite*	*Antigorite*
1	4.265 mm.	4.805 mm.	0.600 mm.	0.900 mm.
2	6.535	2.660	0.850	1.095
3	5.015	3.750	0.390	2.000
4	4.360	0.745	1.140	5.030
5	3.240	0.000	1.350	5.140
6	3.105	2.950	1.030	1.710
7	4.000	1.730	0.615	1.260
8	3.835	0.000	0.370	3.495
9	4.845	1.380	0.490	2.395
10	3.710	1.525	1.435	1.100
11	0.000	3.960	0.720	0.000
12	7.675	2.350	0.950	2.200
13	8.420	1.410	1.125	2.535
14	5.510	1.630	2.410	1.730
15	4.215	5.560	2.315	0.250
Total	68.730	34.455	15.790	30.840

PERCENTAGE COMPOSITION

Minerals	*Percentage*
Labradorite	45.8
Hypersthene	23.0
Magnetite	10.5
Antigorite	20.5
	99.8

Leucocrates make up 45.8 per cent of the whole..Class 3
Plagioclase is labradorite..Order 3
No quartz..Families 9–12
Plagioclase feldspar make up 100 per cent of feldspar..Family 12
Rock number..3312
Rock name..Melagabbro

Since the pyroxene is hypersthene, the rock would be classed as a norite.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 318-339, 9 FIGS.

EXAGGERATION OF VERTICAL SCALE OF GEOLOGIC SECTIONS[1]

H. H. SUTER[2]
Point-a-Pierre, Trinidad, British West Indies

ABSTRACT

Attention is drawn to the fact that many petroleum geologic sections are constructed with exaggerated vertical scale. The distortional effects of this exaggeration are discussed in detail and a plea is made to replace exaggerated sections by true sections. Finally, alternative solutions for the construction of sections through areas of flat geology and/or large basins are suggested, namely, the coupling of a true geologic section with a stratigraphic section.

INTRODUCTION

A casual glance at geological articles in current periodicals such as the *Oil Weekly*, the *Oil and Gas Journal*, or the *Petroleum Engineer*, reveals a preponderance of geological sections with exaggerated vertical scales. Similarly, in text books and in symposia on oil geology there also appear sections with exaggerated vertical scale.

This exaggeration has persisted for a considerable time, in spite of the admonitions of authorities. For example, Frederic H. Lahee in his *Field Geology* (12) in an explicative text to Figure 463, page 612, refers to errors resulting from exaggeration of the vertical scale of a geologic section and says:

> The vertical and the horizontal scales of a geologic section should be the same. Exaggeration of the vertical scale necessitates adjustment of all dips and this . . . gives also a false notion of the structure.

And in a footnote he says:

> Five thousand feet to an inch for the vertical scale (1:60,000) is satisfactory where the horizontal scale is 1 mile to 1 inch (1:63,360) and the same may be said of multiples of these scales.

Lahee thus makes a slight concession to his rule for the sake of speed. For sections drawn in the metric scale, of course, this argument of speed is entirely irrelevant. Lahee's Figure 463, page 617,—a true section and its exaggerated counterpart—shows glaringly the effects of exaggeration.

Bailey and Robin Willis (16) in their text-book, *Geologic Structure*, page 352, give the following advice under the heading "Graphic Methods":

> In drawing cross-sections of regions where the deformation has been pronounced it is most essential that the vertical dimension be on the same scale as the horizontal. If this is not the case, the structures become so distorted that they cannot be correctly interpreted even though correctly drawn. In flat-lying sediments, however, vertical exaggeration may be permitted and the exaggeration may be indicated by breaking the horizontal section into separate columns. Wherever it is used, though, its effect must be constantly borne in mind, otherwise the geologist gradually comes to have an erroneous impression

[1] Manuscript received, June 18, 1946.

[2] Geological department, Trinidad Leaseholds, Ltd.

of the structures with which he deals and may for this reason misinterpret the forces which have formed them.

Evidently, the Willises realize the cumulative psychological conditioning effect of exaggeration and imply that it requires a sustained conscious effort to visualize the correct picture, that is, to translate the exaggerated picture into a correct one.

M. P. Billings in his *Structural Geology* (7) states on page 412:

Generally the vertical scale of a section should be the same as the horizontal scale, otherwise the geological structure becomes distorted. If the strata are horizontal, however, it is sometimes necessary to exaggerate the vertical scale.

Billings also is primarily concerned with the structural aspect of geological sections and he does not give a reason for the last part of his statement.

Let us see what the topographers think of sections with exaggerated scale. C. L. Dake and T. S. Brown in their book *Interpretation of Topographic and Geologic Maps* (10), on page 322 under the heading. "The drawing of Structure Sections," give the following advice:

Undue exaggeration of the vertical scale should be avoided in as much as exaggeration distorts the thickness and the dip of beds and gives an untrue picture of the structure.

The term "undue" is not explained and the student is at a loss where to draw the limit.

Perusal of the fairly recent set of geophysical text-books shows that geophysicists do not seem to be much concerned with the effects of exaggeration of vertical scales; neither do they stress the decrease of dip values on sections oblique to a structure.

Although many authors condemn the drawing of geologic sections with exaggerated vertical scales, yet the custom of exaggeration persists and it should prove interesting to inquire briefly into the relative incidence of, and the reasons for, exaggeration and to suggest possible ways and means to avoid at least some of the more unfortunate consequences of exaggeration.

RELATIVE INCIDENCE OF EXAGGERATION OF VERTICAL SCALE

A few books on petroleum geology and geophysics have been examined for examples of exaggerated and true sections. Well sections, that is, sections built up of well logs only which purport to show primarily well-to-well correlations, have not been counted. Inclusion of such sections would have weighted the counts unduly, since well sections are, in fact, mostly diagrammatic.

The results of this random check are given in Table I.

Indeed, it appears that a large majority of petroleum geological sections are exaggerated. In addition to the text-books listed in Table I, *Oil Finding*, by Cunningham Craig (9), and *Oil Field Exploration and Development*, Vol. 1, by Beeby Thompson (5), have been sampled also. These two texts yielded a rather disappointing picture. Both authors give very few sections. Cunningham Craig gives

only one drawing which could be labelled a section—a true one at that; Beeby Thompson apparently preferred diagrams to sections and dispenses entirely with scales. Both books are full of pictures of oil seepages and of mud volcanoes—an interesting sidelight on the state of oil finding in the early twenties when surface mapping was the principal tool and seepages were the most reliable sign posts to oil fields.

The periodical *Geophysics* contains few sections which can be properly classed

TABLE I

RANDOM SAMPLES OF RELATIVE INCIDENCE OF EXAGGERATED AND TRUE SECTIONS IN PETROLEUM GEOLOGICAL PUBLICATIONS

Source	*Vertical Scale Exaggerated*		*True Scale*		*Total*
	U.S.A.	*Other Countries*	*U.S.A.*	*Other Countries*	*Samples*
Blumer, 1922 (6)	1 (4%)	0	0	27 (96%)	28
Lilley, 1928 (13)	9 (6%)	0	3 (20%)	3 (20%)	15
A.A.P.G. (1), 1929, Structure of Typical Amer. Oil Fields	17 (100%)	0	0	0	17
Emmons, 1931 (11)	33 (42%)	5 (7%)	22 (28%)	18 (23%)	78
A.A.P.G. (2), 1934, Problems of Petroleum Geology	30 (97%)	0	0	1 (3%)	31
A.A.P.G. (4), 1941, Stratigraphic Type Oil Fields	51 (96%)	0	2 (4%)	0	53
A.A.P.G. (3), 1941, Possible Future Oil Provinces*	31 (89%)*	0	4 (11%)	0	35
W. A. Ver Wiebe (14), 1930, Oil Fields in United States	19 (56%)	0	15 (44%)**	0	34
	191	5	46	49	291

* 4 of the exaggerated sections show in addition the surface in true scale (15%).
14 others of the exaggerated sections show surface and part subsurface in true scale (45%).
** 5 of the true sections are of salt domes and the others show pure geology.

as geological and therefore do not give a true picture of the incidence of exaggeration. A rapid count yielded one true section and seven exaggerated ones. In a few cases the fact of exaggeration is noted in the legend, in others neither horizontal nor vertical scales are given.

On the other hand, sections through salt domes are most commonly true to scale. In W. A. Ver Wiebe's book *Oil Fields in the United States* (14), for example, one third of the true sections are of salt domes. Salt domes are relatively small objects and this may be the reason that sections of them are drawn true to scale. Many sections of California geology are also in true scale, especially those published by Ralph Arnold. Apparently California tectonics are acute enough without exaggeration.

A European example of a text book on petroleum geology is that of E. Blumer (6) published in 1922—a remarkably modern and comprehensive text, for its time, which, unfortunately, seems little known. We find therein a representative collection of types of oil structures illustrated by examples from all over the world. Blumer gives almost exclusively true sections. This may not be significant because at that time (1922) structural accumulations were in the limelight; nevertheless, it is significant that the few examples of exaggerated sections he gives are of American origin.

The results of random sampling tabulated on Table I give the following distribution of true and exaggerated sections.

Of all sections counted	(201) 67% are exaggerated 33% are true
*Of American sections counted	(237) 80% are exaggerated 20% are true
**Of European and Asiatic sections counted	(54) 9% are exaggerated 91% are true

* Sections illustrating American geology and almost exclusively by American authors.
** Mostly by European authors.

This distribution may indicate two things. Firstly, the American geologists prefer to use exaggeration of vertical scale by training, habit, or custom, or they have to deal mainly with "flat" geology. Secondly the European geologists either prefer true scale sections by training, habit or custom, or they have to deal mainly with "steep" geology. Perhaps both explanations are valid to a certain extent. However, in more recent American geological papers one can definitely note a trend toward the increased use of true sections. The latest A.A.P.G. symposium on future oil provinces of the United States and Canada (3) is an example of this trend. In this symposium the system of dual or coupled section is adopted and many "conventional," that is, exaggerated sections are accompanied by a true, though commonly incomplete, counterpart.

Perhaps random sampling is not always indicative, but in this case it should give a sufficiently true picture, since the text-books and symposia sampled derived their material largely from previously published papers. In general, on looking through text-books and symposia one can not help noticing that many sections are reprinted and passed from one text to another without any attempt at modernization or standardization of scales, legends, or style of drawing. Many, if not most, of the sections in the books cited are decidedly too small. The latest A.A.P.G. symposium on future oil provinces (3) shows some progress in this respect, yet exaggerated sections still dominate. Apparently geologists have acquired a habit which is difficult to overcome.

EFFECT OF EXAGGERATED VERTICAL SCALE ON STRATIGRAPHY AND TECTONICS

Obviously in extreme cases of exaggeration, the tectonical and the stratigraphical picture become meaningless, even in regions of moderate tectonics; moderate dips can become almost vertical, *et cetera*. Geologists not accustomed to exaggerated sections are apt to forget the fact of exaggeration and will gain a mental picture of acute structural relief when, in fact, the tectonic relief may be very mild. They find it difficult to translate the exaggeration into a true-scale picture; as a result they gain an incorrect impression which, after the conditioning period, becomes their standard mental picture of the geology of a region in the same way that most people carry in their minds a quite erroneous picture of the earth, being conditioned by the constant use of the Mercator projection. It is said that this Mercator projection is responsible for much erroneous geo-politic

thinking and who can truly say that he is able to visualize automatically the true picture.

Exaggeration of vertical scale affects primarily the vertical dimensions of a geological form but it also affects, in a certain way, the horizontal dimension. In the vertical direction the picture is actually expanded; in the horizontal direction it is apparently contracted. The exaggerated section, thus, is like a cylindrical mirror with its well known effects of caricature.

TABLE II

EFFECT OF EXAGGERATION OF VERTICAL SCALE ON DIP

True Dip	*Exaggeration*								
	2x	3x	5x	7x	10x	12x	15x	17x	10x
	Apparent (Exaggerated) Dip								
5°	9°55′	14°42′	23°38′	31°29′	41°11′	46°24′	52°41′	56°05′	60°15′
10°	19°25′	27°52′	41°24′	50°59′	60°27′	64°42′	69°17′	71°33′	74°10′
15°	28°11′	38°48′	53°16′	61°56′	69°32′	72°44′	76°02′	77°37′	79°26′
20°	36°03′	47°31′	61°13′	68°34′	74°38′	77°06′	79°38′	80°49′	82°10′
25°	43°	54°25′	66°47′	72°58′	77°54′	79°52′	81°51′	82°48′	83°53′
30°	49°06′	60°	70°53′	76°06′	80°10′	81°47′	83°25′	84°10′	85°03′
35°	54°28′	64°32′	74°03′	78°28′	81°53′	83°13′	84°35′	85°12′	85°55′
40°	59°13′	68°20′	76°35′	80°20′	83°12′	84°20′	85°27′	85°59′	86°35′
45°	63°26′	71°34′	78°41′	81°52′	84°18′	85°15′	86°12′	86°38′	87°09′
50°	67°14′	74°22′	80°28′	83°10′	85°12′	86°	86°48′	87°10′	87°30′
55°	70°42′	76°52′	82°02′	84°17′	86°	86°40′	87°20′	87°39′	88°
60°	73°54′	79°06′	83°25′	85°17′	86°42′	87°14′	87°47′	88°03′	88°20′
65°	76°52′	81°10′	84°40′	86°11′	87°20′	87°46′	88°13′	88°26′	88°40′
70°	79°41′	83°05′	85°50′	87°02′	87°55′	88°15′	88°37′	86°46′	88°57′
75°	82°22′	84°54′	86°56′	87°49′	88°28′	88°43′	88°58′	89°06′	89°14′
80°	84°58′	86°38′	87°59′	88°33′	88°59′	89°10′	89°20′	89°24′	89°30′

EFFECTS OF VERTICAL EXPANSION

Vertical expansion causes distortion of dip and thickness of beds and this distortion varies with true dip and ratio of exaggeration, that is, the resulting apparent dip is the product of the factor of exaggeration times the tangent of the true dip. The apparent stratigraphic thickness varies with the ratio of the sine of true dip divided by the sine of the apparent dip.

For one and the same ratio of exaggeration the difference between true and apparent dip decreases with increasing true dip, and for one and the same true dip the relative increase is smaller the greater the exaggeration. Some actual values of exaggerated dips are given on Table II.

Table IIIA gives a few examples of the exaggeration of the stratigraphic thickness. For an exaggeration of five times, the stratigraphic thickness increases from unit to 4.5 for a dip of 5°, while it increases only to 1.6 for a dip of 30°. For an exaggeration of 10 times, the corresponding figures are 7.5 and 1.97. For an exaggeration of twice, a true dip of 5° increases almost 100% while a true dip of 55° increases by less than 30%, and likewise for the same exaggeration the stratigraphic thickness of a bed dipping 5° increases by almost 100%, while for the

same bed dipping at 55° it increases only by 15%. Figure 1 shows these relations in a graphic form.

In a section of a faulted area this means that upon exaggeration a bed of unit thickness will appear thicker in the gentler than in the steeper-dipping block; in

TABLE III

EFFECT OF EXAGGERATION ON STRATIGRAPHICAL THICKNESS
Reduction of Apparent Unit Stratigraphic Thickness for Various Dips and Exaggerations to True Stratigraphic Thickness

True Dip	*Exaggeration*								
	2x	3x	5x	7x	10x	12x	15x	17x	20x
	Reduction Factor								
5°	.506	.343	.217	.167	.132	.120	.109	.105	.100
10°	.522	.372	.262	.223	.200	.192	.186	.183	.180
15°	.548	.413	.323	.293	.276	.271	.267	.265	.263
20°	.581	.464	.390	.367	.355	.351	.347	.346	.345
25°	.619	.519	.460	.442	.432	.429	.427	.426	.425
30°	.661	.577	.529	.515	.507	.505	.503	.502	.502
35°	.705	.635	.596	.585	.579	.577	.576	.575	.575
40°	.748	.691	.661	.652	.647	.646	.654	.644	.644
45°	.790	.745	.721	.714	.711	.709	.708	.708	.708
50°	.831	.795	.777	.771	.769	.768	.768	.767	.766
55°	.868	.841	.827	.823	.821	.820	.820	.819	.819
60°	.901	.882	.872	.869	.867	.867	.866	.866	.866
65°	.931	.917	.910	.908	.907	.907	.906	.906	.906
70°	.955	.946	.942	.941	.940	.940	.940	.940	.939
75°	.974	.969	.967	.966	.966	.966	.966	.966	.966
80°	.988	.986	.986	.985	.985	.985	.985	.985	.985

Apparent stratigraphic thickness×reduction factor = true stratigraphic thickness.

TABLE IIIA

INCREASE OF STRATIGRAPHIC THICKNESS WITH INCREASING EXAGGERATION

True Dip	*Exaggeration*								
	2x	3x	4x	7x	10x	12x	15	17	20x
	Apparent Stratigraphical Thickness								
5°	1.98		4.55		7.5				10
15°	1.83		3.10		3.6				3.8
30°	1.60		1.88		1.97				2.
40°	1.34		1.51		1.54				1.55
55°	1.15		1.20		1.21				1.22

Example.—True unit stratigraphic thickness increasing to apparent thickness 1.98 for a bed dipping 5° at an exaggeration of vertical scale of two times.

a section of a folded area, upon exaggeration the same bed of unit thickness will appear to be thicker in the syncline or on the crest than on the flanks of the fold. Figure 2 (a section through an ideal anticline) shows these relations and effects graphically. Crests become thicker and thicker, flanks relatively thinner and thinner. The unwary observer of a section with strong exaggeration of vertical

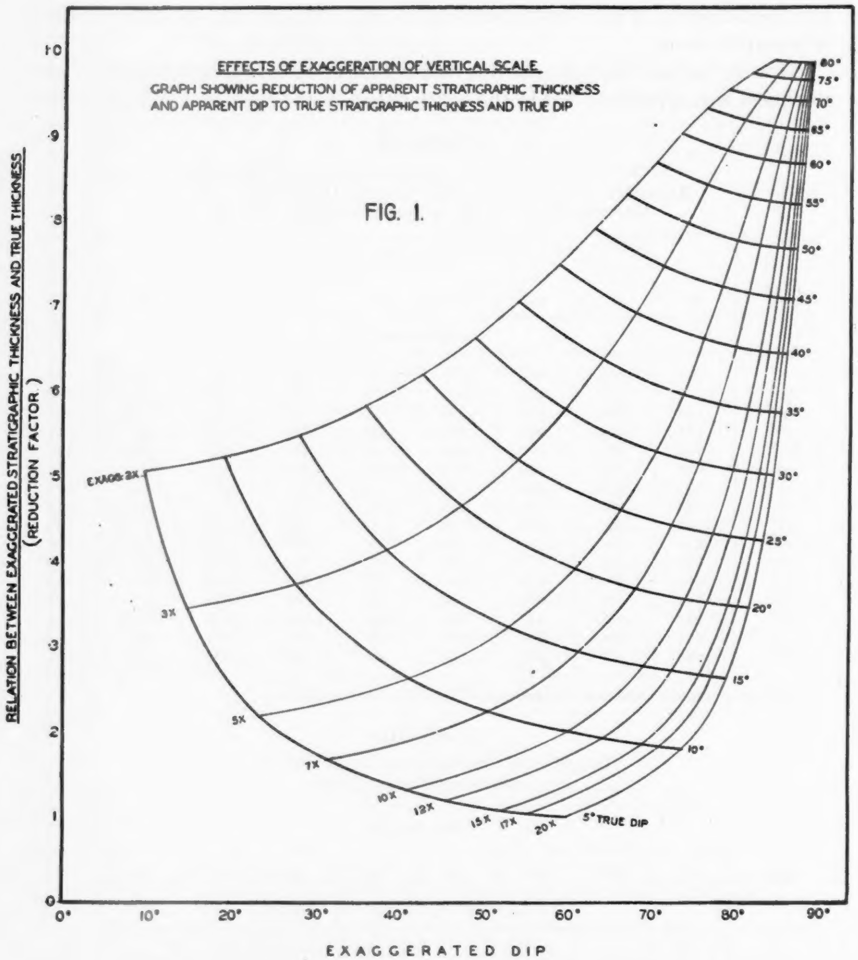


FIG. 1.—Plot of apparent dips against ratio of apparent to true stratigraphic thickness for various degrees of exaggeration and various true dips.

scale showing flattish dips on one end and very steep dips on the other end of the section will be inclined to conclude that beds are thinning from one end of the section to the other. This "thinning effect" is illustrated in Figure 7, a section through West Virginia after Theron Wasson and Isabel E. Wasson. The authors wisely added an explanatory remark to the legend.

The distortional effect of exaggeration on dip of faults and beds is also a source of confusion, for the steeper the true dip the smaller the increase in dip for

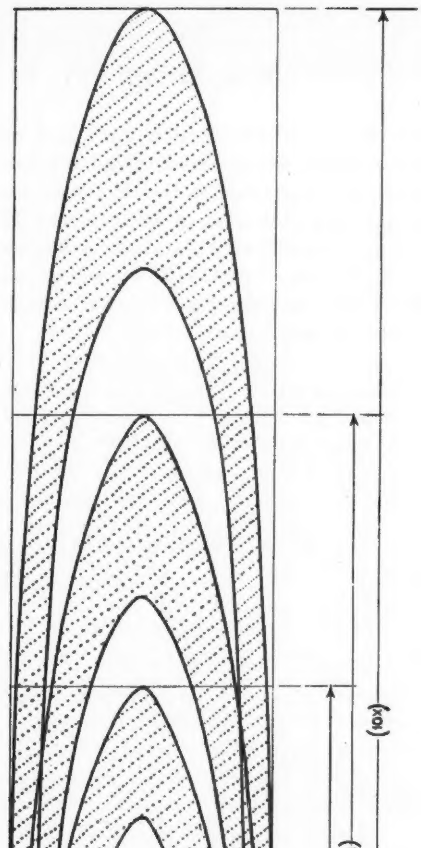


FIG. 2.—Effect of exaggeration of vertical scale on stratigraphic thickness and dips on a bed of unit thickness of an ideal anticline.

a given exaggeration. An exaggerated section of a region with uniformly dipping faults and symmetrical anticlines remains intelligible because the distortion will be uniform. However, an exaggerated section of a region with variably dipping faults and with asymmetrical anticlines will become very difficult to read or unintelligible once the exaggeration of vertical scale exceeds three times the horizontal scale. Differences in dip will be minimized and it will be impossible to gauge differences in true dip. A low-angle dip-slip fault can become a high-angle normal fault at an exaggeration of only 5 times.

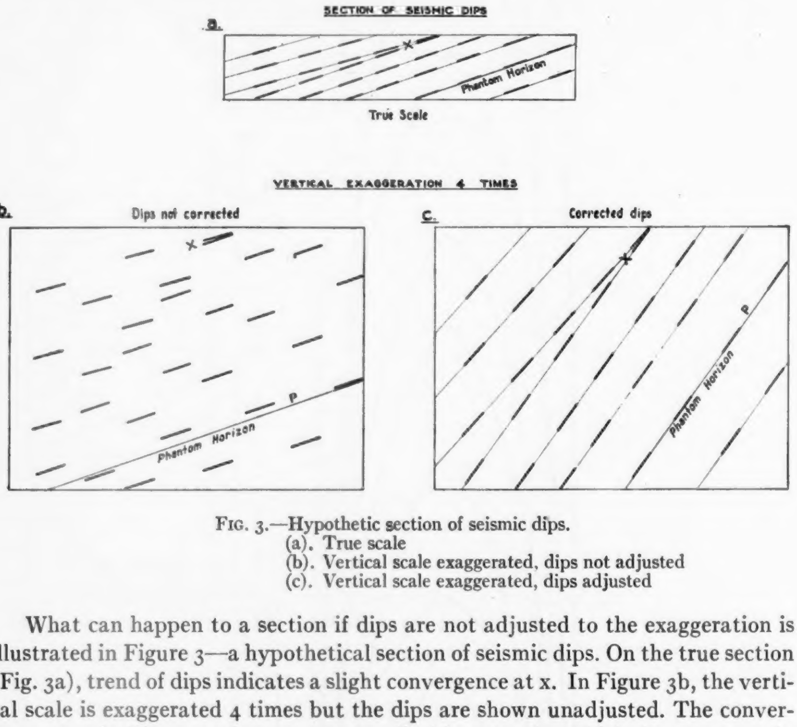


FIG. 3.—Hypothetic section of seismic dips.
(a). True scale
(b). Vertical scale exaggerated, dips not adjusted
(c). Vertical scale exaggerated, dips adjusted

What can happen to a section if dips are not adjusted to the exaggeration is illustrated in Figure 3—a hypothetical section of seismic dips. On the true section (Fig. 3a), trend of dips indicates a slight convergence at x. In Figure 3b, the vertical scale is exaggerated 4 times but the dips are shown unadjusted. The convergence at x in Figure 3a is now an unexplicable anomaly, which, however, again appears in Figure 3a when dips are adjusted, that is, exaggerated in conformity with the exaggeration of the vertical scale. Note also the difference in dip of the phantom horizon in Figure 3b and Figure 3c. Seismic dip sections are constru ted from isolated dips and if dips are not adjusted to the exaggeration very misleading sections can result.

In summary, the effect of expansion is one of irregular distortion of the true dimensions of beds and of the true attitude of structural elements, and this may be known as the *differential distortional effect of exaggeration.*

EFFECT OF HORIZONTAL CONTRACTION

The principal horizontal or lateral effect of exaggeration of vertical scale is to bring every element of a section closer together. On local sections this is not so disturbing as it is on regional ones. A normal basin, for example, contains a certain number of geological accidents, for example, folds, faults, wedge edges. On an exaggerated section one or two folds plus, say, one fault can monopolize, so to speak, the space and can give the impression that the full complement of geological accidents is shown. The feeling is created that the basin has been completely explored and that its features are completely known when, quite possibly, there may be a few more anticlines awaiting discovery and when there may be more faults of regional significance and perhaps more shore lines in the basin. The presence of these additional features is not suspected because the section appears saturated. Likewise, the thickness of strata appears to be immense and the geologist files the sections with the impression that the basin has been fully explored and that further attention is unwarranted.

The impression created by horizontal contraction of a section may be termed *the saturation effect of exaggeration.*

EFFECTS ON OIL-FIELD SECTIONS

While the effects already discussed are very noticeable on regional sections, they appear, too, although perhaps in milder form on exaggerated sections across an individual oil field. Exaggeration of vertical scale can convert a familiar picture—the true section—into a very unfamiliar and indeed strange one, as illustrated in Figure 4, a section through the Forest Reserve field of Trinidad, B.W.I. Figure 4a is a true section (after R.O. Young and K. W. Barr) and Figure 4b is the same section with the vertical scale exaggerated five times. A comparison between the two versions will show that the dip of the faults has changed very little but the beds now dip at enormously increased angles. The exaggeration is clearly superfluous since it does not bring out more details. There can be little argument about which type of section gives a more natural picture, even for one unfamiliar with the structural style of the Trinidad district of the Orinoco oil province. It may be mentioned here that exaggeration of vertical scale is not practiced in Trinidad.

PSYCHOLOGY OF EXAGGERATION

The oldest geological sections were all diagrammatic, that is, their vertical scale was greatly exaggerated. Some time elapsed before geologists adopted the habit of indicating scale. This is easy to understand because the first topographic drawings, for example, of mountains, were exaggerated. The tendency to draw "true" sections grew by necessity mainly under the impact of Alpine and Rocky Mountain geology. When the anatomy of complicated objects such as the Alps or the Rocky Mountains is exposed over a height of several thousands of feet any attempt to use exaggeration is quickly quelled by the unintelligible results.

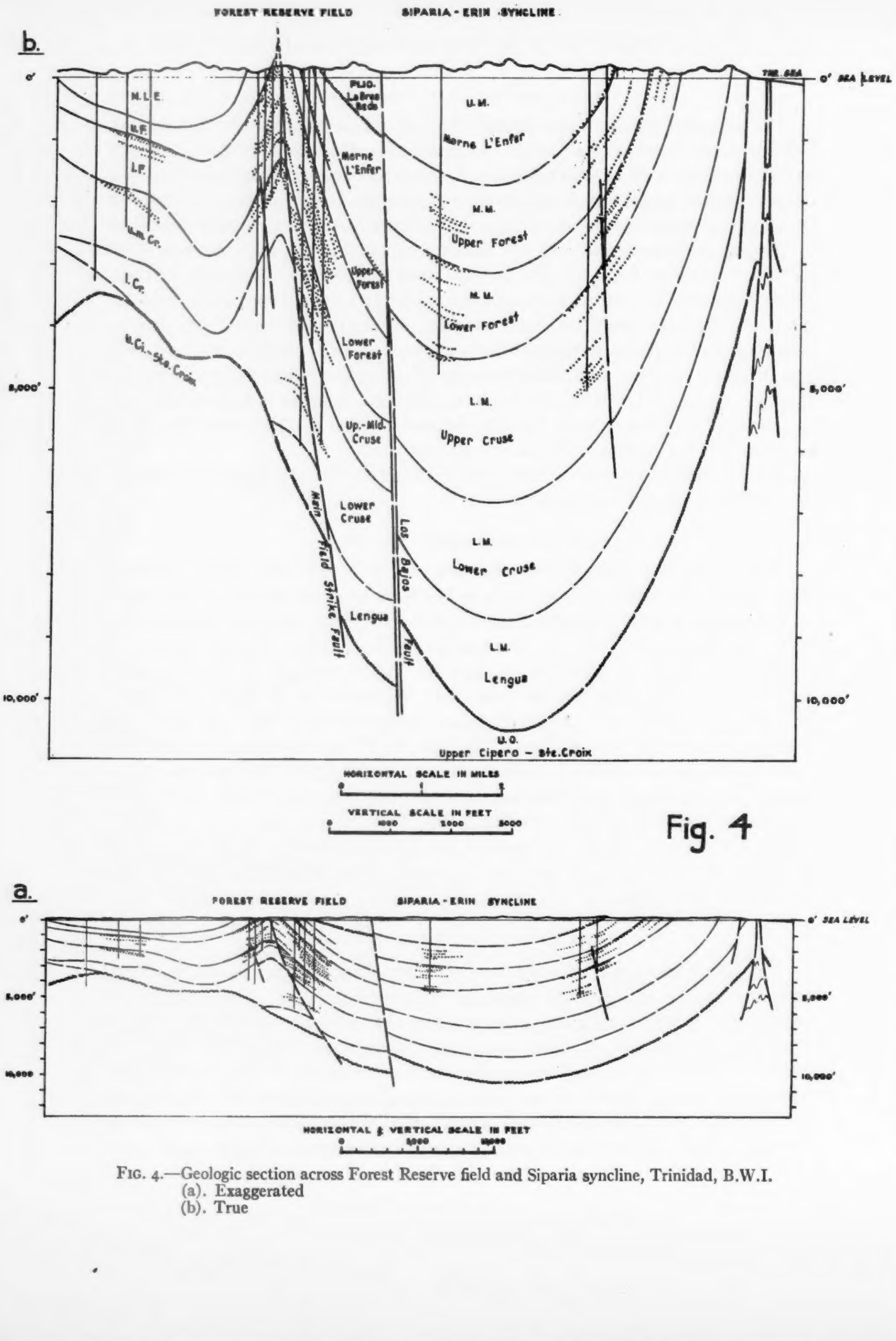


FIG. 4.—Geologic section across Forest Reserve field and Siparia syncline, Trinidad, B.W.I.
(a). Exaggerated
(b). True

To-day, structural geologists are strongest in condemning the practice of exaggerating vertical scales, simply because they feel most handicapped by the effects of exaggeration. One example may suffice: of the sections in Bucher's monographic book, *The Deformation of the Earth's Crust* (8), 63% are true, 39% are diagrammatical and only 3% are exaggerated. Geologists working in regions of "flat" geology apparently have no strong predilections and the habit of exaggeration persists possibly as a matter of convenience or results from a genuine feeling that "true" scale sections, although desirable, are insufficient or too long to show the essentials, which, for the petroleum geologist, more often than not are sedimentational rather than structural features. Nevertheless, the undesirable effects of exaggeration are an invitation to look for a more logical solution of the graphic problems involved not only for theoretical but also for very practical reasons. It is not wholly improbable that on one or the other occasion exaggeration with its saturation and distortional effects may have affected discovery thinking and rather deferred than encouraged the finding of an additional structural or even stratigraphic trap.

WHEN CAN EXAGGERATED SECTIONS BE USED?

Nobody, of course, will be so dogmatic as to condemn entirely the use of exaggerated vertical scales. Obviously, it is necessary to consider the purpose for which a section is to be constructed and the region through which it is to be laid. Geological sections illustrate structure and sedimentation. In the ideal case, these two objects can be shown in true scale simultaneously on one and the same section which then is a true "geological" section. Conditions for the construction of a true geological section are ideal when the region to be depicted is small or the data available are so scanty that two or three lines suffice to show all that is known.

Flatness of dip is no reason for exaggeration; neither is scarcity of faults; nor is the fact that a section is to be regional a sufficient motive to warrant an exception to the first rule of section drawing, which says: "Sections must be constructed true to scale." Exceptions to this rule are condoned, for example, by Lahee as a matter of convenience, by Willis for regions of flat dip, if the section is broken up into columns, and also by Billings if only stratigraphy is to be shown. Exceptions should only be made for definite reasons and not as a matter of simple convenience. Some seem permissible in the following cases.

1. Exceptions from the rule of true scale seem permissible for well sections or diagrams, of individual oil fields where single beds must be shown in great detail for a specific purpose and the space for reproduction is definitely limited. Well sections are usually constructed by plotting logs and there is no danger of introducing unadjusted, that is, false, dips.
2. For sections of single, individual, geological features free of structural complications such as faults, flexures, or folds. Such sections are almost columnar.

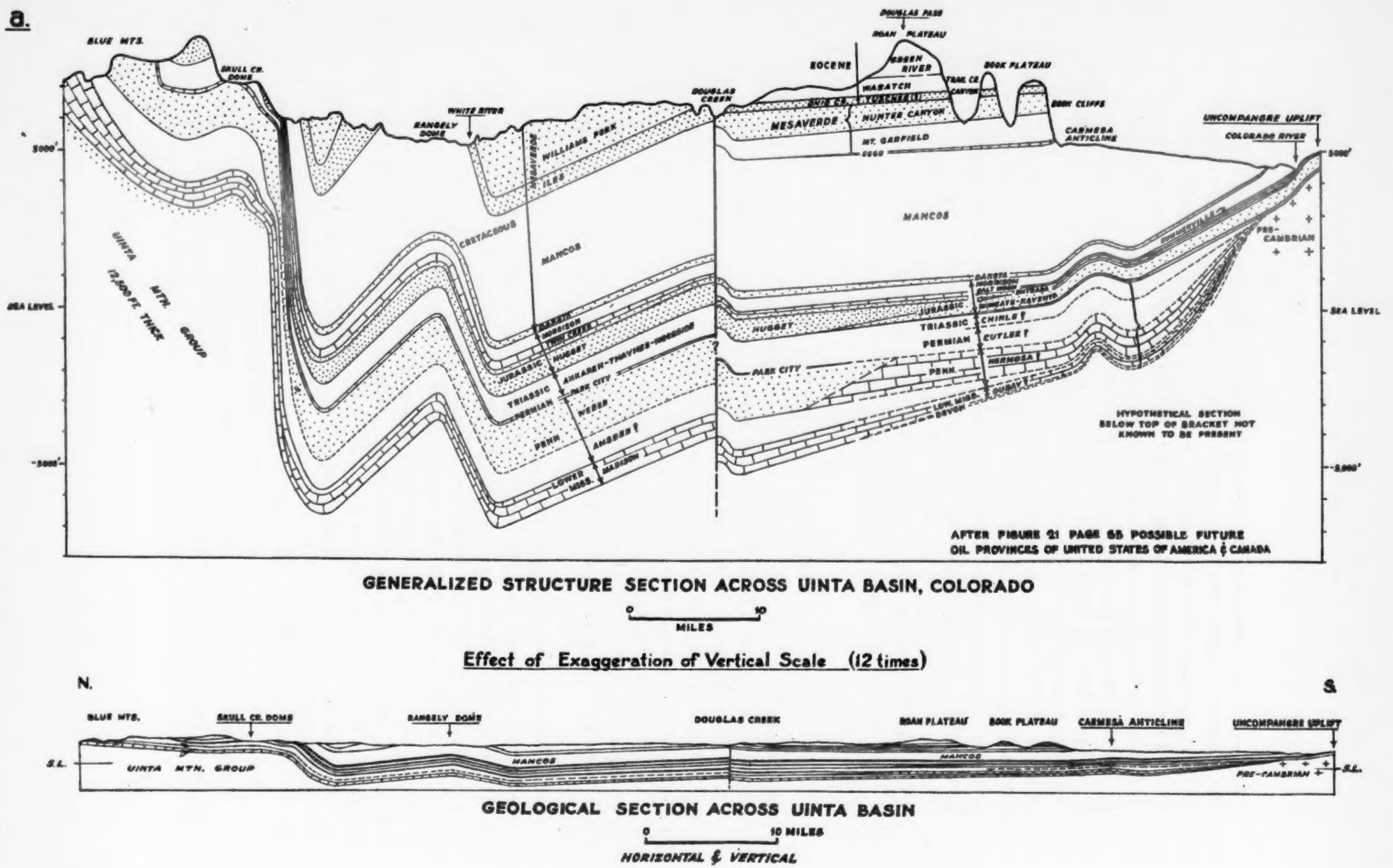


FIG. 5.—Geological section across Uinta Basin, Colorado.
(a) Exaggerated geologic section.
(b) True-scale geologic section.

3. For single outcrops (natural or artificial) for technical purposes, where the question of the horizontal dimension hardly enters.

Perhaps there are other exceptions but, in general, for local and regional (especially the latter) sections, the rule should remain—no exaggeration of vertical scale.

READING OF EXAGGERATED SECTIONS

It is certain that exaggerated sections will continue to appear in trade journals and in professional papers. In order to read them it is necessary to either memorize a basic amount of data such as the relations between true dip and exaggerated dip and between true stratigraphical thickness and apparent thickness. For this purpose tables and graphs have been constructed, for example, by G. H. K. Wentworth (15). For the sake of convenience, however, two tables (II and III) and a graph (Fig. 1) have been prepared for this paper. The graph may take the place of the tables and is meant rather as an aid to read exaggerated sections than as an aid to construct them. The graph can be used to solve the following type of problem.

Known:	Exaggeration of vertical scale	5×
	Apparent stratigraphical thickness of bed (measured on section)	1,000 ft.
	Apparent dip of bed (measured on section)	71°
Sought:	True stratigraphical thickness and true dip	
Solution:	On Fig. 1: Find on abscissa 71°, go along ordinate to intersection with the curve for 5× exaggeration, read true dip on true dip curve (30°), move from the same point of intersection, left along abscissa and read on left hand scale the reduction factor (0.529) from which calculate the true thickness (1000×.529 = 529 ft.)	

Of course, to a certain extent, constant analysis of exaggerated sections might or should enable the geologist to gauge mentally the effects of exaggeration of vertical scale and to dispense with tables and graphs.

However, before resorting to exaggeration, a geologist should always ask himself: "Is exaggeration really unavoidable or can the problems in hand be shown satisfactorily by a true section?" If the answer is in the negative, he should then attempt to use one of the methods described in the following paragraphs, and if not satisfactory he may then have to exaggerate the vertical scale in the "conventional" way.

FURTHER EXAMPLES OF EXAGGERATED SECTIONS AND ALTERNATIVE SOLUTIONS

The problem is to show on one section true structure with sufficient stratigraphical details; various solutions are known. The U. S. Geological Atlas, for example, makes use of "interrupted sections"; the A.A.P.G. symposia make use of the device of "coupled" or "dual" sections.

COUPLED SECTION

In Figure 5a an exaggerated section through the Uinta basin is reproduced. This section has appeared in almost all of the well known trade journals and in the A.A.P.G. symposium on future oil provinces (3). One of the latest reproductions

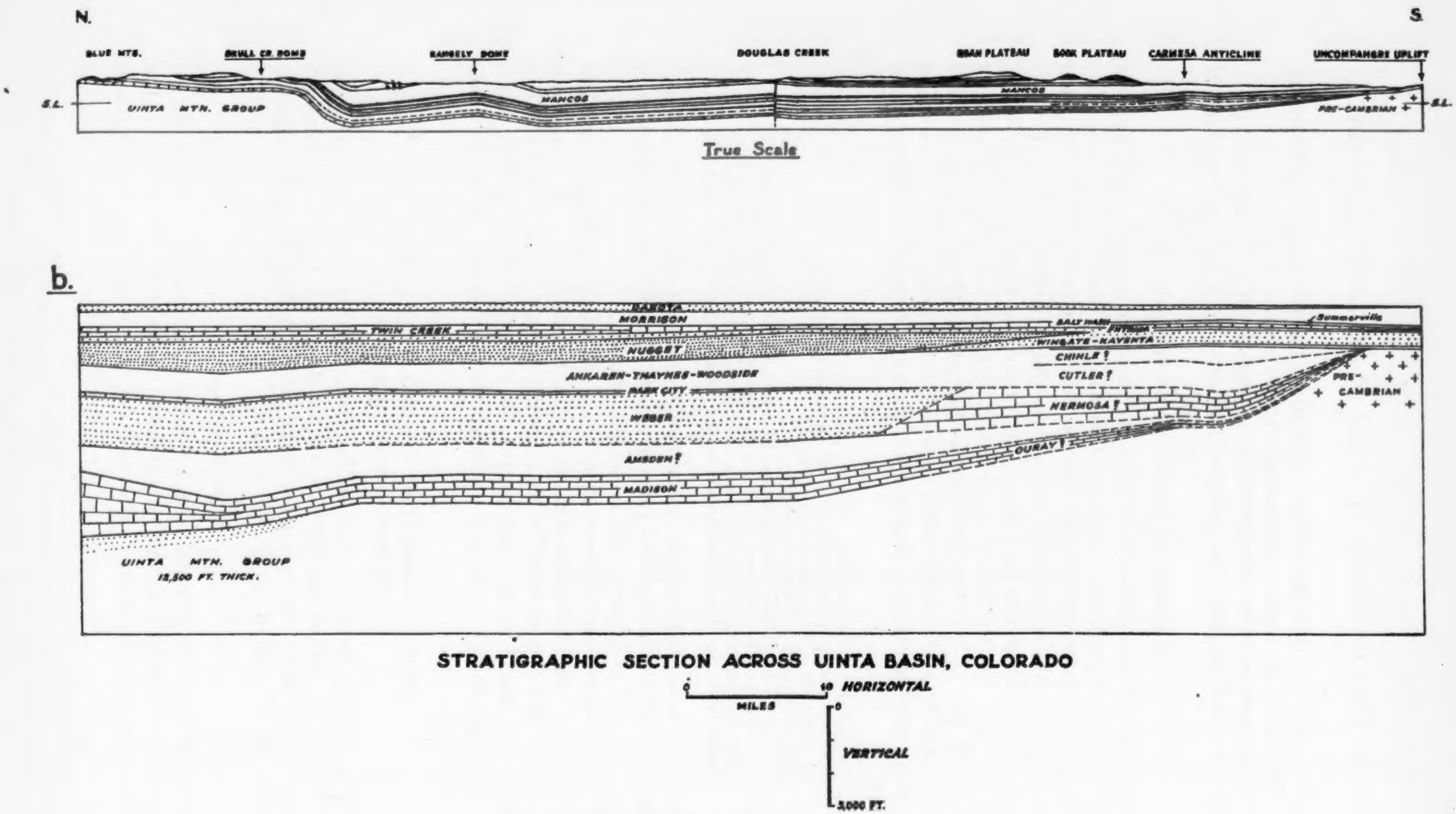


FIG. 6.—Same section as in Figure 5.
(a). True geologic (the same as true section (b) of Figure 5).
(b). Exaggerated stratigraphic section.

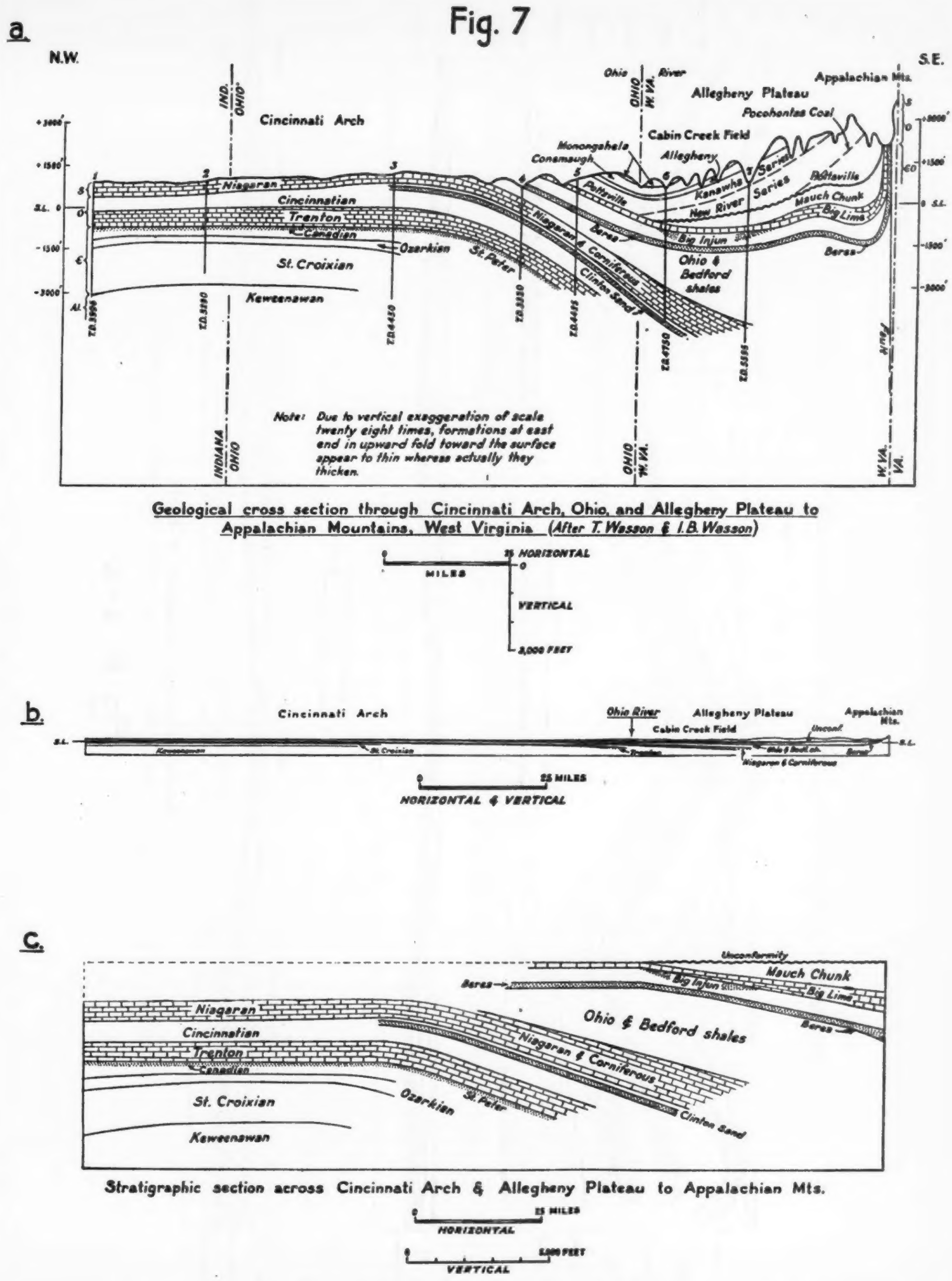
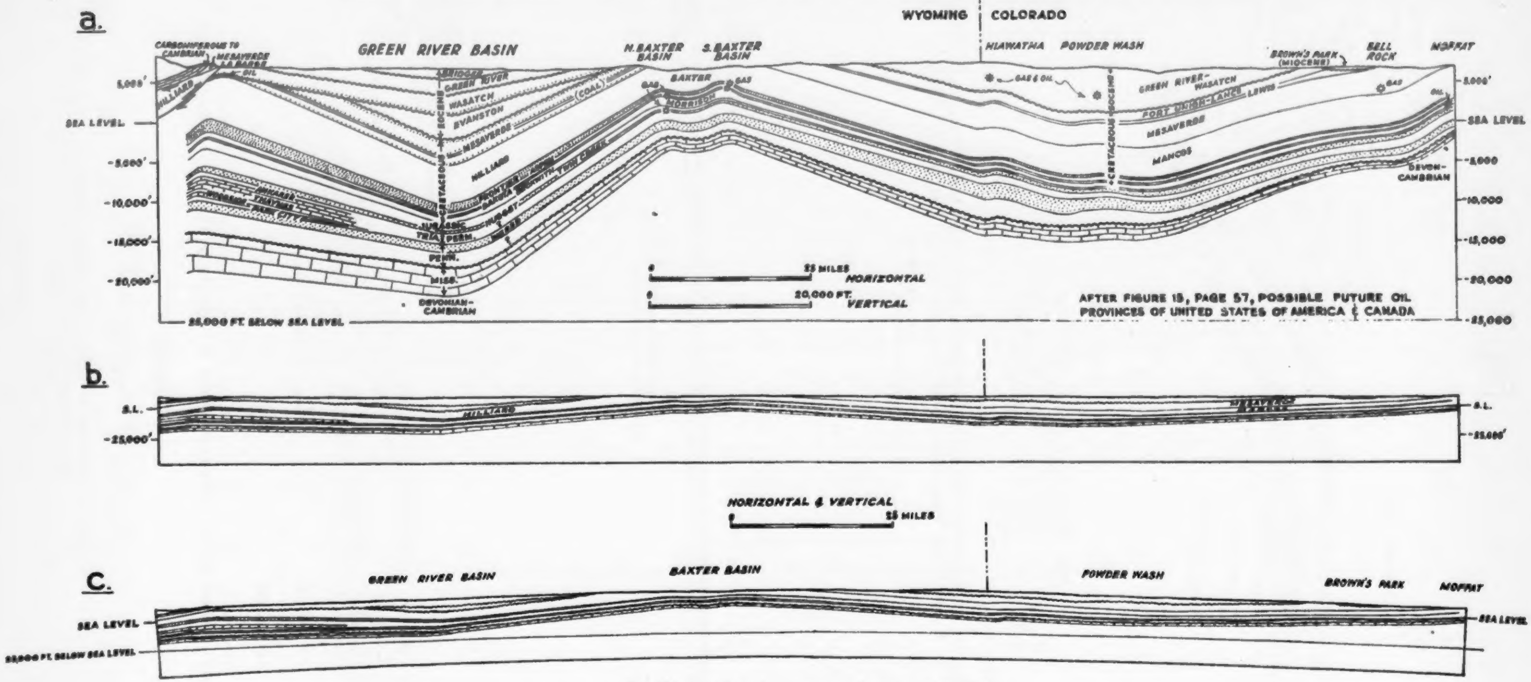


FIG. 7.—Geologic sections across West Virginia
(a). Exaggerated geologic
(b). True geologic
(c). Exaggerated stratigraphic

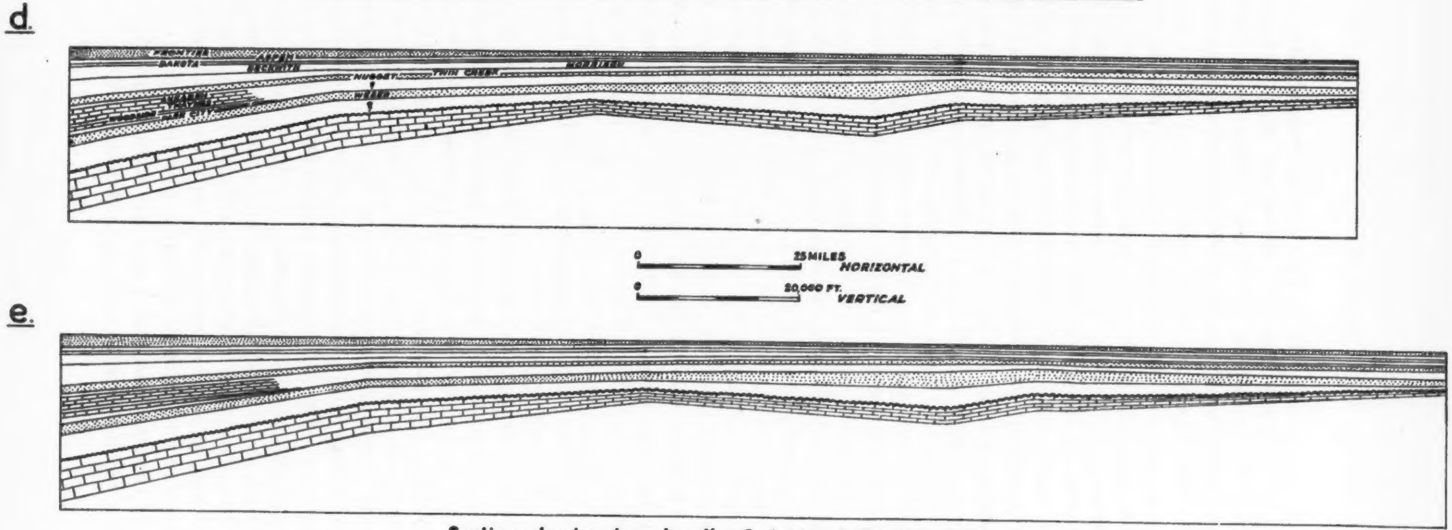
GENERALIZED STRUCTURE SECTION ACROSS GREEN RIVER BASIN, WYOMING AND COLORADO



Section showing curvature of Earth

Fig. 8 a-e

STRATIGRAPHIC SECTION ACROSS GREEN RIVER BASIN, WYOMING AND COLORADO



Section showing true length of strata at Frontier level

FIG. 8.—Geologic section across Green River Basin, Wyoming, Colorado
(a). Generalized geologic exaggerated
(b). True geologic—base line flat
(c). True geologic—base line true to curve of level
(d). Stratigraphic vertical projection
(e). Stratigraphic key bed flattened

was in connection with an article by E. F. Estergren on deep-drilling reserves, Rangely field, Colorado (*Petroleum Engineer*, December, 1945). Estergren uses this section to illustrate the regional relations of the Rangely dome, which is said to show 13°–21° dip on the southwest flank and 6° dips on the northeast flank. On the section itself these dips appear to range between 40° and 70° due to exaggertion of vertical scale. A wealth of stratigraphical details is shown, however distorted by exaggeration, especially in the south flank of the Skull Creek dome, the flank of which appears unnatural and extremely attenuated (obviously, no place for drilling). The Carmesa anticline, though not indicated on the surface, appears to be a major feature, the nature of which is difficult to understand. The Douglas Creek fault monopolizes attention; this fault appears to have major proportions and to have caused enormous drag. In fact, it appears to cut vertically through the crest of an anticline, formed by fault drag. One feels there is hardly any room left in the basin for further anticlines, neither major nor subsidiary ones, and there seems to be space for only one major zone of faulting. Apart from showing distorted geology, the section is truly saturated with geological accidents. The question is: "Was exaggeration necessary? and how does a true scale version look?" In Figure 5b the true scale version is given. At once the dips become "natural" and the saturation effect is absent. There are no deep cañons in the Book Plateau, and there is plenty room for more than one additional fault or tectonical high. Stratigraphical relations are still discernible in astonishing detail. Was exaggeration really necessary? To pursue the subject further, in Figure 6 the same true section is given, this time as a couple, that is, the corresponding stratigraphic section has been added. The stratigraphic section has been constructed with the Dakota sand as horizontal base line. This section couple seems to supply all the information one could wish to have. The true version gives a true picture of the structure and the stratigraphical version gives truer stratigraphical details than the exaggerated section.

A further example of an exaggerated section is shown in Figure 7a, a section through the Cincinnati arch (after a section in Emmons' *Geology of Petroleum* (11). This is an extreme case of exaggeration. The vertical scale is 28 times the horizontal one. The Allegheny side of the section is distorted beyond recognition; beds appear to dip vertically and there seem to exist violent unconformities and some beds seem to thin rapidly over apparently short distances. The note in the legend, however, draws attention to the exaggeration and its consequences. Figure 7b now shows the true version of the same section and Figure 7c its stratigraphic counterpart. The true section, while not giving details is still clear enough to convey the essentials of the structure, namely, the shallow basin in the Allegheny sector; the stratigraphical counterpart gives as much stratigraphical details as the exaggerated section but much more correctly and intelligibly.

Figure 8 may serve as a final example of exaggeration and will further emphasize the suitability of true sections. It is a regional section through the Green River Basin. The true version (Fig. 8b) contains practically all the information

the author wishes to convey to the reader; even such a detail as the Hiawatha structure at the state line between Colorado and Wyoming is still clearly visible on the true version. There is no actual need in this case to add a stratigraphic section at all. However, for the sake of comparison, this has been added in Figure 8d.

Apropos the subject of stratigraphical sections, a point of method seems to be open to dispute. In Figure 8d the section has been constructed in the conventional way without taking account of the curvature of the beds. On the version 8e account has been taken of the curvature of the key bed and the result of flattening of the key bed (Frontier) is a lengthening of the section. It is doubtful whether this flattening is of any advantage from a practical standpoint.

The Green River Basin is about 25 miles wide along the trace of the section and to be absolutely true a section should take into account the curvature of the surface of the earth. This curvature is shown in Figure 8c and it is clearly discernible. There is, in this case, little to choose between a conventional and a curved true section, and this subject of curvature is not discussed further in this paper.

The A.A.P.G. symposium, *Stratigraphic Type Oil Fields* (4), contains some sections more or less true to scale, among them some through the Edison field, which show a wealth of details and are thus further examples of the suitability of true sections.

The examples of coupled sections given should suffice to prove that this method of illustrating geology is feasible; moreover, in two of them the true section is satisfactory in itself.

INTERRUPTED SECTIONS

By the term "interrupted section" is meant a section which shows selected finite fractions of a large section lined up along a base line. Lateral contraction is accomplished by omitting part of the original section and by closing the rank of the chosen fractions. Usually, but not necessarily, the fractions are selected at a definite spacing interval and so that the information omitted does not distort the structure. Figure 9a shows an example of an interrupted section. The problem was to show the position of the edge-water line without distorting the dip of the oil horizon, whilst still showing stratigraphy in sufficient detail. The author of the original section, which section is not reproduced here, chose the method of exaggerated vertical scale, which fulfilled all his postulates with the exception of the dip, which appears distorted of course. The true section (Fig. 9b) in this case is wholly insufficient. A stratigraphical section is out of question; however, as Figure 9a shows, an interrupted section seems to solve the dilemma satisfactorily without the loss of vital information.

CONCLUSION

These few examples of coupled or dual and interrupted sections should suffice to show that there is little need for drawing sections with exaggerated vertical

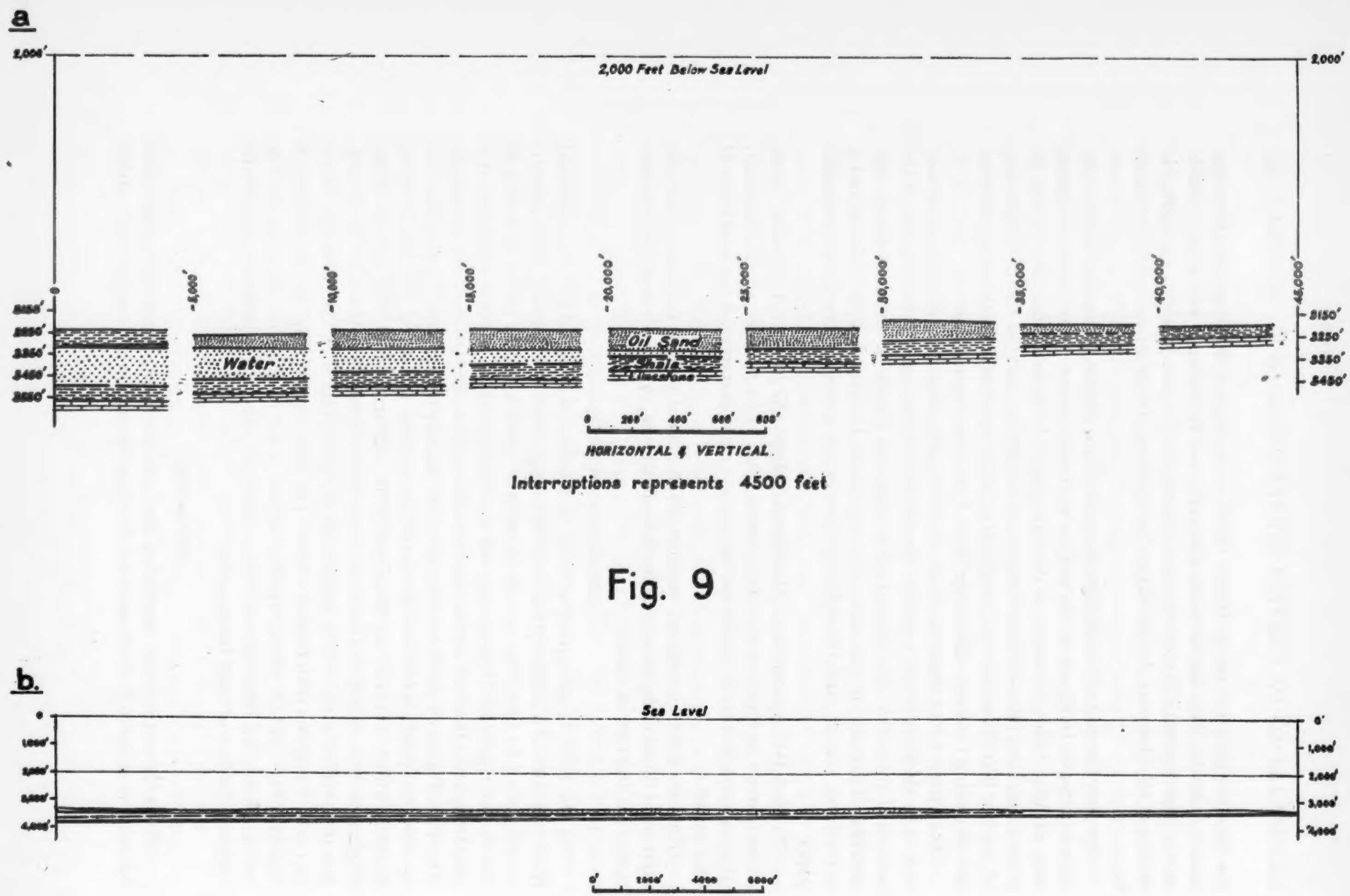


FIG. 9.—Geologic section across Longview area, East Texas; (a) Interrupted section; (b) True scale. Modified from Stratigraphic Type Oil Fields, p. 624, Fig. 9.

scale, all the more so if attention is paid to the purpose for which a section is needed. When the object to be sectioned is a regional one, for example, a large basin, a true section will commonly show at least the type of prevailing crustal deformation. If it is desired to show stratigraphic details a companion section of the stratigraphic type may be added. When the purpose of the section is to show specific oil-field problems, the method of interrupted sections may be used with advantage.

It is probably no exaggeration to say that there are few geological provinces which can not be depicted satisfactorily on true, coupled, or interrupted sections, and that the need for exaggeration of vertical scale is much smaller than it appears to be if judged solely by the apparent prevalence in present publications of exaggerated sections.

BIBLIOGRAPHY

1. *Structure of Typical American Oil Fields*, Amer. Assoc. Petrol. Geol. (1929).
2. *Problems of Petroleum Geology, ibid.* (1934).
3. *Possible Future Oil Provinces of the United States and Canada, ibid.* (1941).
4. *Stratigraphic Type Oil Fields, ibid.* (1941).
5. Beeby Thompson, *Oil Field Exploration and Development*, Vol. 1 (1925).
6. Blumer, E., *Die Erdoellagerstaetten*, Stuttgart (1922).
7. Billings, M. P., *Structural Geology* (1942).
8. Bucher, W. H., *The Deformation of the Earth's Crust* (1941).
9. Cunningham Craig, E. H., *Oil Finding* (1921).
10. Dake, C. L., and Brown, J. S., *Interpretation of Topographic and Geologic Maps* (1925).
11. Emmons, W. H., *Geology of Petroleum* (1931).
12. Lahee, F. H., *Field Geology* (1941).
13. Lilley, E. R., *The Geology of Petroleum and Natural Gas* (1928).
14. Ver Wiebe, W. A., *Oil Fields in the United States* (1930).
15. Wentworth, Chester K., "Plotting and Measurement of Exaggerated Sections," *Econ. Geol.*, Vol. 25 (1930), pp. 827–31.
16. Willis, B. and R., *Geologic Structures* (1934).

Fig. 9.—Geologic section across Longview area, East Texas; (a) Interrupted section; (b) True scale. Modified from Stratigraphic Type Oil Fields, p. 624, Fig. 9.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 340-349, 2 FIGS.

LOG MAP, NEW TYPE OF SUBSURFACE MAP[1]

T. H. BOWER[2]
Point-a-Pierre, Trinidad, British West Indies

ABSTRACT

This paper describes what is believed to be a new type of subsurface map. It is essentially a structure-contour map, on which variations in the lithological succession of a formation, member, or smaller unit are depicted by a series of electric or other logs. The name "log map" is conveniently applied to this type of map.

Since an attempt is made to provide a three-dimensional picture on a two-dimensional surface, limitations are placed on the clarity and completeness of the map by the thickness of the selected formation interval, the well spacing and the scales used.

With the addition of appropriate data the map is an extremely useful tool in the analysis of subsurface geology, as a location plan, and as a reservoir map upon which the development of reservoirs can be planned and followed.

INTRODUCTION

Modern exploitation methods, as applied to the complex structural and multiple-sand conditions of the oil fields of Trinidad, B.W.I., could not be satisfactorily served by conventional structure-contour maps, sections, and isopach maps. Realizing this inadequacy, A. L. Payne of Trinidad Leaseholds, Ltd., developed in 1938, a sand-distribution map that can be considered the prototype of the present log map. The sand-distribution map consisted of a series of electrical profiles of a stratigraphical unit and was used to study variations in thickness and facies. By adding suitable data the map was adapted during the subsequent 5 years to the routine uses described in this paper. The addition of contouring on a particular horizon within the mapped unit provided a three-dimensional picture which greatly facilitated the elucidation of the subsurface geology and the development of the various oil fields operated in Trinidad by Trinidad Leaseholds, Ltd.

DEFINITION AND IDENTIFICATION OF MAPPED UNITS

The technique used in the definition and identification of the mapped units is primarily dependent on the stratigraphy of the area concerned.

Where the lithological and faunal facies of the units which it is desired to map vary rapidly in a vertical direction, each unit is readily recognizable by the combined use of lithological and paleontological determinations and interpretation of the electric profile. Commonly, however, as in the case of the Miocene sediments of Trinidad, faunal criteria can be used only in the identification of units of formation rank. In such cases subdivision of the stratigraphic sequence into smaller units is dependent on the correlation of the electrical profile between individual wells.

[1] Manuscript received, June 18, 1946.

[2] Geologist, Trinidad Leaseholds Ltd. The writer wishes to extend his thanks to the Management of Trinidad Leaseholds, Ltd. for permission to publish the maps and the information contained in this paper and to his colleagues of the Geological Department for their part in developing the map and for assistance in compilation.

Thus the middle Cruse member of the Miocene Cruse formation (Forest Reserve field of Trinidad Leaseholds, Ltd.) within the area depicted in Figure 1 is identified as a unit by recognition of a lithological sequence of which the electrical profile is distinct from that of the overlying and underlying members.

Within the middle Cruse member illustrated in Figure 1 further subdivision into sand zones, which can be economically produced as individual units, is likewise dependent on the correlation of the electrical profiles of lithological sequences. This method was used in the construction of the log map (Fig. 2) of the basal 586 sand zone of the middle Cruse member of Figure 1. Lateral lithologic variations commonly render difficult the positive identification of units of the rank of a sand zone. Corroborative fluid physical data may be required to substantiate the correlation of electrical profiles.

CONSTRUCTION PROCEDURE

A standard sheet outline is first prepared, preferably on durable material such as Kodatrace. The surface positions of all wells are plotted by co-ordinates. Wells not penetrating the unit to be mapped are differentiated from those entering the unit and those passing through the unit by suitable symbols.

The subsurface position of the chosen contour horizon is then plotted with respect to the surface position of the well from the directional deviation survey.

Where only non-directional deviation surveys are available, the horizontal displacement of the contour horizon from the surface position of the well is calculated assuming the drift to be in a direction consistent with that of directionally surveyed wells in a comparable structural and stratigraphical position. Where non-directionally surveyed wells are surrounded by directionally surveyed wells the position of the contour horizon in the non-directionally surveyed wells is plotted as inferred from the contouring between the directionally surveyed wells.

The relevant portion of the electrical log (or other type of log) is then drawn on the map with the contour horizon at the position on the map calculated from the deviation survey. In order to conserve space laterally the resistivity and self potential curves of the electrical profile are drawn as close together as is consistent with the amount of information to be shown in the space between them. The depth of the contour horizon with respect to the chosen datum level is printed on the map immediately at the right of the position of this horizon, positive or negative signs preceding the figures to indicate height above or depth below the datum level.

The fluid content of the sediments penetrated is not evident in the case of old wells for which only a gamma-ray log or driller's log may be available. Appropriate symbols indicating the fluid content are drawn beside these logs where coring evidence provides this information.

The addition of contouring on the chosen horizon, of other structural symbols, and of further appropriate data enables the finished map to be used for a variety of purposes as described in subsequent sections of this paper.

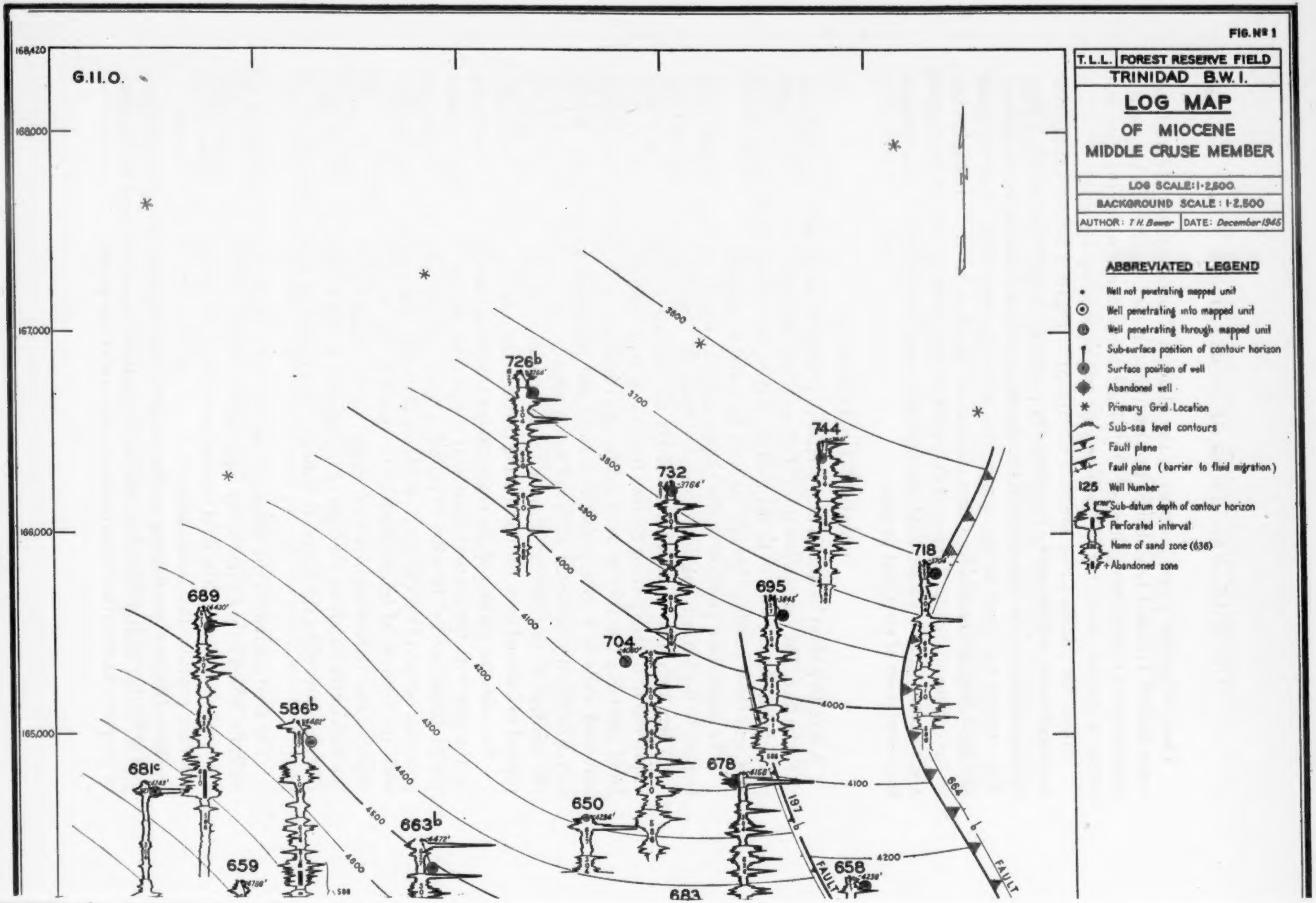
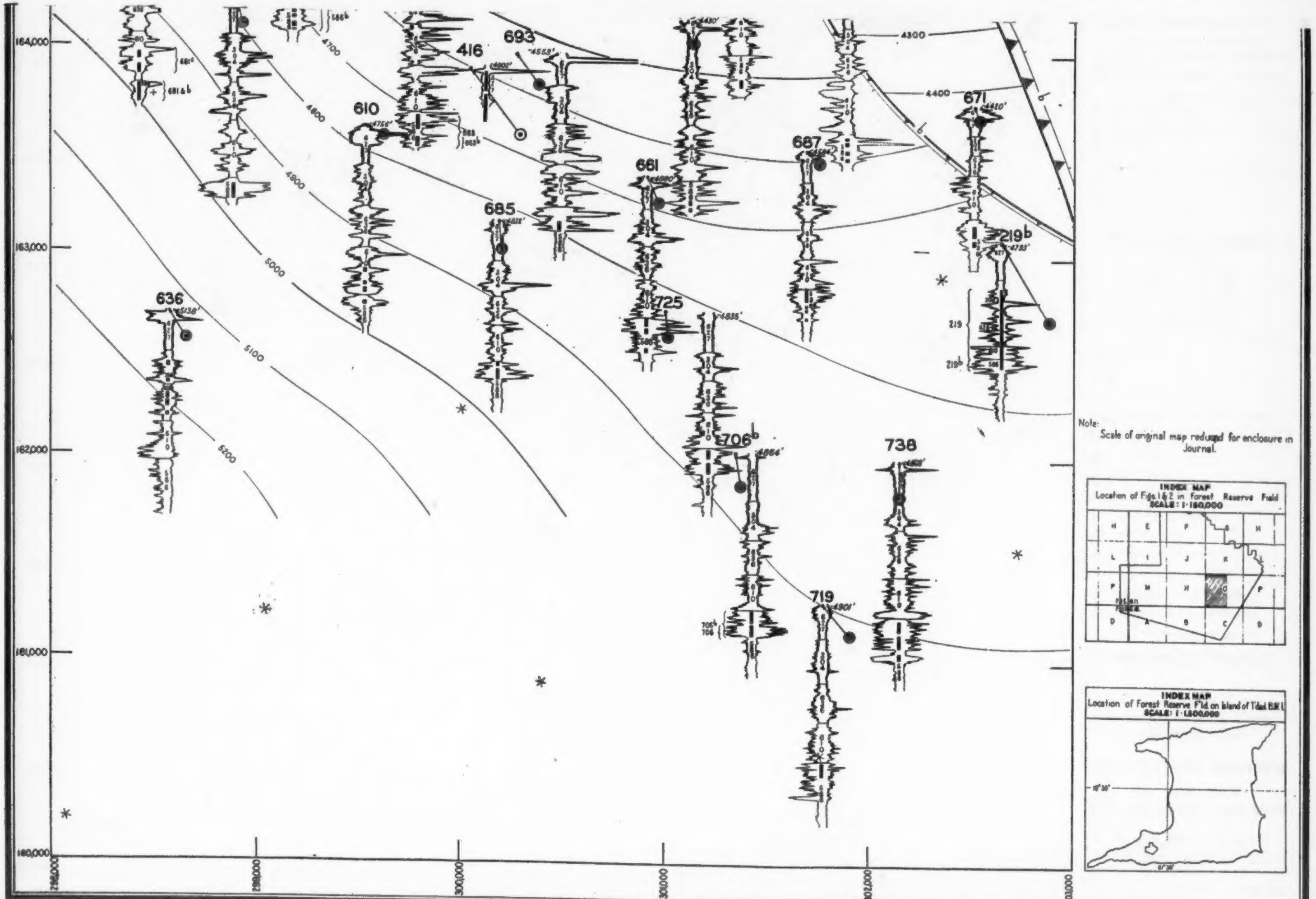


FIG. Nº 1
T.L.L.
FOREST RESERVE FIELD
TRINIDAD B.W.I.
LOG MAP
OF MIOCENE
MIDDLE CRUSE MEMBER
LOG SCALE: 1·2,500
BACKGROUND SCALE: 1·2,500
AUTHOR: T.H. Bower
DATE: December 1945
ABBREVIATED LEGEND
Well not penetrating mapped unit
Well penetrating into mapped unit
Well penetrating through mapped unit
Sub-surface position of contour horizon
Surface position of well
Abandoned well
Primary Grid Location
Sub-sea level contours
Fault plane
Fault plane (barrier to fluid migration)
125 Well Number
Sub-datum depth of contour horizon
Perforated interval
Name of sand zone (636)
Abandoned zone
G.11.O.
168,420
168,000
167,000
166,000
165,000
FAULT
FAULT
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
4600
726b
744
732
718
689
704
695
586b
681c
678
650
663b
659
658
683
664
197



164,000
163,000
162,000
161,000
160,000
298,000
299,000
300,000
301,000
302,000
303,000
4300
4400
4700
4800
4900
5000
5100
5200
FAULT
416
693
610
685
661
687
671
219b
636
725
706b
738
719
Note:
Scale of original map reduced for enclosure in Journal.
INDEX MAP
Location of Figs. 1 & 2 in Forest Reserve Field
SCALE: 1:150,000
INDEX MAP
Location of Forest Reserve Fld. on Island of Tdad. B.W.I.
SCALE: 1:1,500,000

FIG. 1

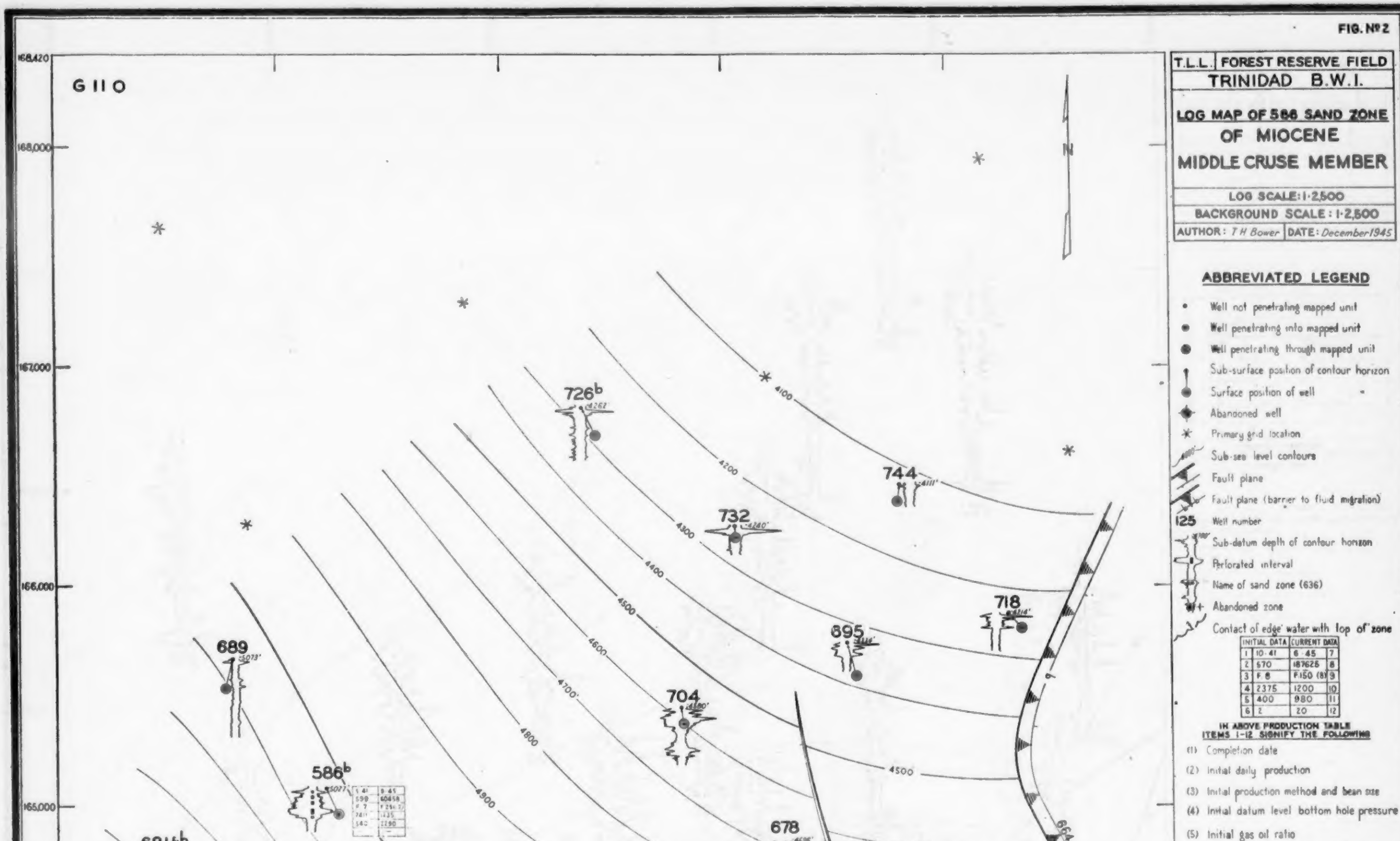


FIG. Nº 2
T.L.L. FOREST RESERVE FIELD
TRINIDAD B.W.I.
LOG MAP OF 588 SAND ZONE
OF MIOCENE
MIDDLE CRUSE MEMBER
LOG SCALE: 1·2,500
BACKGROUND SCALE: 1·2,500
AUTHOR: T H Bower
DATE: December 1945
ABBREVIATED LEGEND
Well not penetrating mapped unit
Well penetrating into mapped unit
Well penetrating through mapped unit
Sub-surface position of contour horizon
Surface position of well
Abandoned well
Primary grid location
Sub-sea level contours
Fault plane
Fault plane (barrier to fluid migration)
125 Well number
Sub-datum depth of contour horizon
Perforated interval
Name of sand zone (636)
Abandoned zone
Contact of edge water with top of zone
IN ABOVE PRODUCTION TABLE ITEMS 1-12 SIGNIFY THE FOLLOWING
(1) Completion date
(2) Initial daily production
(3) Initial production method and bean size
(4) Initial datum level bottom hole pressure
(5) Initial gas oil ratio
(6) Percentage salt water to total fluid
(7) Date of latest bottom hole pressure determination
(8) Cumulative production to above date
(9) Production method, average daily production rate and bean at above date
(10) Datum level bottom hole pressure at
G 110
FAULT b
664
168,420
168,000
167,000
166,000
165,000
726b
744
732
718
895
704
689
586b
681 a b
663b
650
678
659
658
683
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
5100
N

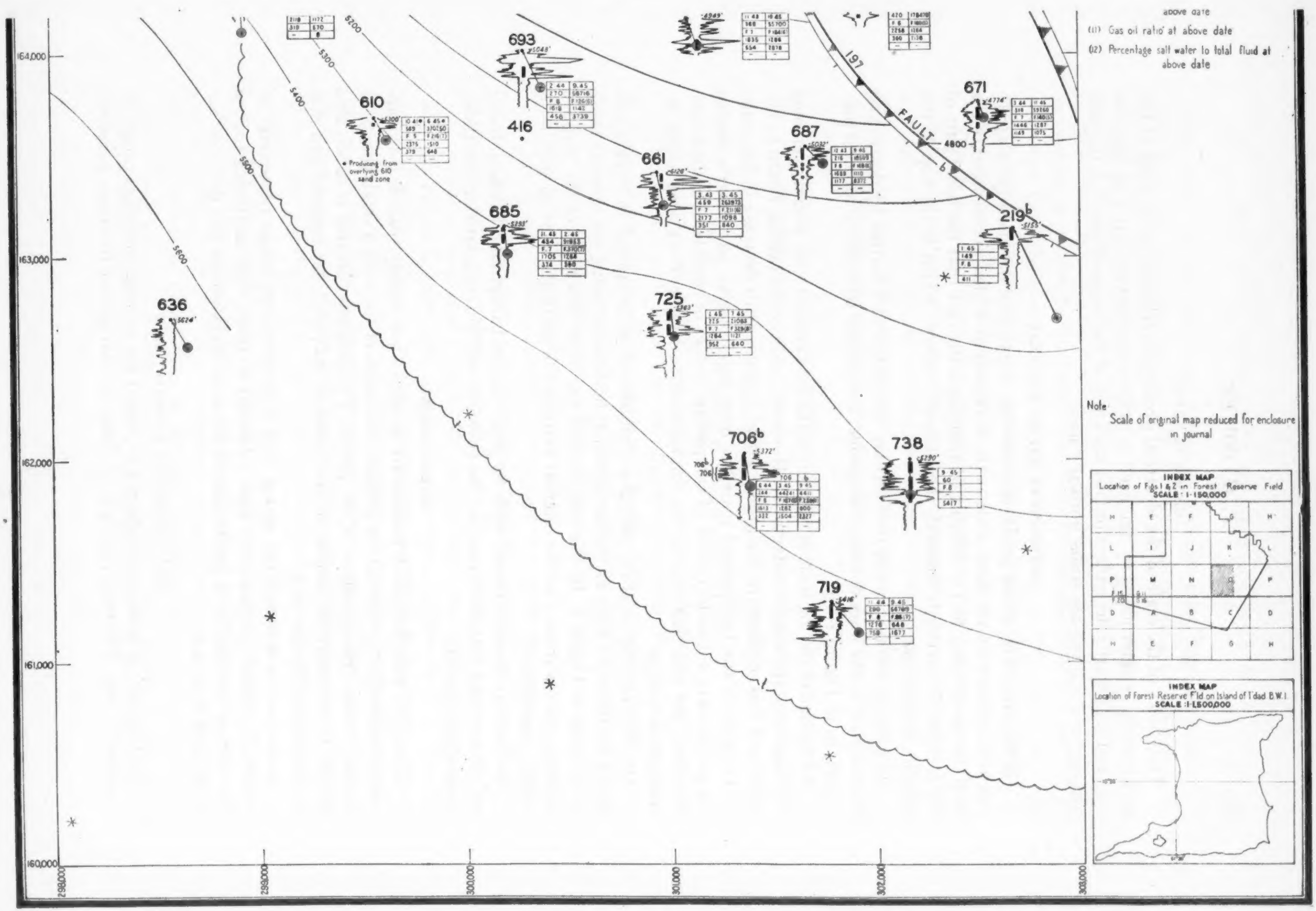

above date
(11) Gas oil ratio at above date
(12) Percentage salt water to total fluid at above date
Note
Scale of original map reduced for enclosure in journal
INDEX MAP
Location of Figs 1 & 2 in Forest Reserve Field
SCALE 1:150,000
INDEX MAP
Location of Forest Reserve Fld on Island of T'dad B.W.I.
SCALE 1:1,500,000
FAULT
197
4800
636
610
693
416
685
661
687
671
219b
725
706b
738
719
Producing from overlying 610 sand zone
5200
5300
5400
5500
5600
164,000
163,000
162,000
161,000
160,000
298,000
299,000
300,000
301,000
302,000
303,000

FIG. 2

CHOICE OF SCALE

The choice of the scale of the electrical profiles, in relation to the scale of the background, is determined by the need to achieve maximum clarity of the final map and is primarily dependent on: (a) thickness of the mapped interval; (b) well spacing; and (c) well log scales normally used.

THICKNESS OF MAPPED INTERVAL

On the map (Fig. 1) the profile of a member, varying in thickness from 540 to 750 feet, is drawn on the same scale as the background. Unless accustomed to the map the reader may find it difficult to appreciate the fact that the basal part of the member is vertically beneath the contour horizon, which is the top of the member in this case.

An attempt has been made to overcome this undesirable feature by decreasing the boldness of the lines defining the profile, toward the base of the interval portrayed, as in Figure 1.

Reduction of the log scale in relation to the background scale would overcome this disadvantage more satisfactorily. However, additional drafting would be entailed and loss of detail in the profile would increase with decrease in log scale.

Increase in the background scale has been found useful, particularly during the preliminary subsurface work of comparing profiles of considerable thickness. However, the resulting map is too cumbersome to handle if the area under investigation is large.

On the map (Fig. 2) the profile of a sand zone of 70 to 240 feet in thickness is drawn on the same scale as the background, both scales being the same as those of the map of Figure 1. In this case, due to the lesser thickness of the mapped interval, the occurrence of the interval vertically beneath the contour horizon is readily appreciated.

For most purposes an equal scale for both log and background has been found satisfactory and with little practice the geologist will obtain a satisfactory three-dimensional picture.

WELL SPACING

When the wells for which profiles are available are closely spaced, it is commonly impossible to draw all the profiles. For some of the wells a small columnar section is then drawn in place of the profile. The columnar section is subdivided equally to represent the number of sand zones of the particular mapped unit that are penetrated by the well.

Reduction in well spacing means that a progressively larger percentage of electrical profiles is replaced by such columnar sections, thus sacrificing part of the value of the map as an illustration of the sand development and fluid content of the unit depicted.

WELL-LOG SCALES NORMALLY USED

In Trinidad, it is standard practice to record the primary electrical profile on a scale of 1:500. The resulting log is too large to manipulate for many purposes;

consequently, all logs (including gamma-ray and formation logs) are reduced, by hand, by using a pantograph, to a scale of 1:2,500, since this scale has been found the most practically useful one.

The map scales commonly used are 1:2,500, 1:5,000, and 1:10,000.

Since the reduction of a log from 1:500 to the 1:2,500 scale is a time-consuming operation, particularly when all the mechanical details of the well are shown on the reduced log as well, it is economical to use only one scale of log, except for very special purposes, even to the extent of sacrificing to a degree the clarity of some of the log maps made.

Clearly from the foregoing considerations, in order to retain maximum clarity and ease of construction of the final map, a compromise must be made between the thickness of the interval depicted, the log scale, the background scale, the well spacing, the shape of the spacing pattern in relation to the edges of the map, the number of electrical and other type of profiles drawn, and the additional data drawn on the map.

Experience shows that a scale of 1:2,500 for both log and background is suitable for most purposes.

USES OF LOG MAPS

USE AS A BASIS FOR ANALYSIS OF SUBSURFACE GEOLOGY

Log maps are basically structure-contour maps and as such are used in structural elucidation and illustration. Substantiating evidence for certain structural features may be apparent from the electrical profiles shown on the log map. Thus, in Figure 1 the presence of the "197" fault is evident from the contouring and substantiated by the difference in fluid content of the "610" sand zone at comparable depths on either side of the fault plane.

When detailed correlation between profiles of a particular member is good, repetition or elimination of portions of the member by faulting allows the trace of the fault plane to be readily mapped.

Consistent thinning of a particular mapped unit, which is clear from the log map, provides an immediate clue to the structural differences to be found in underlying units. Thus the log map functions qualitatively as an isopach map and furthermore enables lateral variations in units composed of a rapidly changing lithological succession to be portrayed and appreciated. In these cases single isopach maps fail to convey the true significance of the variations and a multiplicity of such maps is required to convey what is immediately apparent from the log map.

Variations in lithological facies can be traced and thus the replacement of individual reservoir sands by clay can be outlined. For instance, in Figure 2 the basal portion of the "586" sand zone is replaced by clay in a northerly and westerly direction. Comparison of similar variations may establish significant trends along which sand zones are replaced by clay. Such trends, supported by paleontological evidence, may lead to the delineation of ridges along which the

deposition of sand occurred, while in the adjacent troughs colloidal clays with a deeper-water fauna were laid down. This knowledge is valuable for exploitation drilling.

The progressive disappearance of sand zones as a result of erosion at an unconformity and the progressive overlap of sand zones on to a submarine topographic feature are immediately apparent from the log map, provided that the correlation of individual sand zones can be established. In a similar manner foreset bedding can be detected.

USE AS A LOCATION MAP

The plotting of grid or non-grid locations on a vertical succession of these maps provides location maps surpassing in value the simple location map on which no subsurface data are recorded.

Assessment of the prospects of any location in any horizon may be made, provided that subsurface information in the form of electrical profiles and production data is available within reasonable proximity.

During the active exploitation drilling of any sand zone, the performance of individual wells draining the zone is followed and recorded on the map, in order that the desirability of drilling the remaining locations may be continuously reviewed. Thus the development of a secondary gas cap within any sand zone may be followed on the log map of that zone and the drilling of locations that are, from structural considerations, within the secondary gas cap, can be obviated.

Log maps are invaluable in the drafting of drilling programs for individual locations. The depths of all sand zones that will be penetrated, and the completion depth to the base of the objective sand zone are immediately available.

Since production data are recorded on the maps, the depths at which intermediate strings of casing must be set, to avoid loss of circulation into sands that blew out in old wells, or are seriously depleted, can be readily obtained. Mud weights for the control of all sand zones penetrated can be calculated from the bottom-hole pressure data recorded without reference to numerous filed records.

USE AS RESERVOIR MAPS

The guiding principles of development policy in Trinidad generally are: (1) the subdivision of the stratigraphical succession into sand zones which should and can be produced as units; (2) the areal subdivision of these sand zone units into reservoirs, defined by such geological features as faults and changes in lithological facies that are barriers to fluid migration; (3) the production of oil from these reservoirs so as to attain maximum efficiency of drainage from each reservoir as a whole, rather than maximum oil recovery from individual wells.

The co-ordination of development under this policy is achieved through the medium of the log map.

Vertical subdivision of the stratigraphical succession into sand zones and preliminary areal subdivision of each sand zone into reservoirs is the first step, and

is a geological problem, essentially based on the interpretation of electrical profiles.

The preliminary subdivision into sand zones, based largely on the geological interpretation of electrical profiles, may result in the association, as a producing unit, of individual sand zones or sub-zones with different physical characteristics, so that both areally and vertically final delimitation of reservoir units is a physical problem.

During the period between the initial geological delimitation of reservoirs and the final proof of the physical unity of each reservoir, and also during the subsequent production history, it is clearly advantageous to maintain in readily acessible form, a record of the pertinent data concerning each reservoir.

For this purpose the log map of every sand zone is converted into a reservoir map by the addition of appropriate data.

The fact that the sand zone is either open to production at present, or is not yet perforated for production, or is abandoned, is indicated on the map of each sand zone.

The migration of gas caps is followed on the map by a succession of front lines, joining the subsurface position of the sand zone in those wells, in which the zone last produced pure gas or oil with a gas-oil ratio exceeding an arbitrarily selected limit.

The positions of the original contact of the edge water with the top and base of the sand zone are drawn on the map as edge-water lines. The coning of edge water as production proceeds is symbolized by indentation of these lines. Thus, anomalous entry of gas or water into the production of any well by leakage from above or below, on account of faulty cement jobs, is evident by reference to the map on which the development of a particular reservoir is being followed.

Initial and current production data are compiled and printed on the map as a small table beside the profile of the sand zone in each well.

All permanent data are drawn or printed on the maps in ink and production data which change as the development of a particular reservoir proceeds are printed in pencil and replaced as required. Prints are taken off at intervals and a history of the development of each reservoir is thus preserved.

Log maps are thus a valuable tool in the elucidation of subsurface geology and in the planning and control of reservoir development. Data which are frequently compiled in filed records or on several types of maps and sections are combined upon a single map and are instantly available for inspection and evaluation.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 350-366, 10 FIGS.

ELECTRICAL RESISTIVITY AN AID IN CORE-ANALYSIS INTERPRETATION[1]

G. E. ARCHIE[2]
Houston, Texas

ABSTRACT

A correlation of permeable rock characteristics is important to advance our understanding of rock structure in general as well as help in a practical way to detect oil reservoirs exposed in a bore hole and produce the reservoirs efficiently. Although rocks are heterogeneous and relations between their characteristics cannot be expressed by true mathematical equations, these relations do follow definite trends.

The electrical resistivity which is found useful in outlining different formations exposed in a bore hole, is found to be closely related to total porosity. The type of rock structure, provided it is well consolidated, that is, fine-grained sandstone, coarse-grained sandstone, oölitic limestone, *et cetera*, has remarkably little effect, notwithstanding the heterogeneity and marked variation between different types. This is fortunate because the resistivity log can be used in a more quantitative way.

A comparison of connate water *in situ*, determined by resistivity curves, with residual fluid in contaminated or flushed cores resulted in an empirical relation between the two. The residual water in flushed cores at the surface is approximately 20 per cent higher than the connate water *in situ*. Residual oil (gravity, gas-oil ratio, and viscosity being nearly constant) is also related to connate water.

INTRODUCTION

Correlations between core-analysis data and electrical-resistivity measurements in the laboratory and in the field are given in the hope of arriving at a better understanding of rock structure and the interpretation of core-analysis data.

Permeable rocks are by nature heterogeneous in the true sense, yet as with other natural phenomena, their characteristics, when many data are considered, follow definite trends. It is, therefore, desirable to think of relations of rock. characteristics as trends and not as being rigid and following a particular formula, An average line drawn through numerous data may be expressed algebraically but it must be kept in mind that appreciable deviations from the average may occur.

A study of these trends improves the general understanding of the characteristics, and the scattering of points around the trend shows that the use of a few individual data can be very hazardous. The less uniform the data, the less rigid will be the average relation. Some permeable rocks are more heterogeneous than others. The generally uniform types are sandstones, oölitic limestones, and the so-called granular-appearing dolomites. The less uniform types are the so-called vesicular, vugular, or cavernous, or even fractured limestones and dolomites. This paper deals in part with a correlation of electrical resistivities of the uniform types of porous rocks completely saturated with brine *versus* porosity and permeability measurements.

[1] Manuscript received, June 21, 1946.

[2] Shell Oil Company, Inc. The writer thanks the Shell Oil Company for permission to publish this paper, and the many individuals who devoted generously of their time and efforts to aid in this study. The Shell Production Laboratory, under the supervision of H. S. Rockwood and M. A. Westbrook, made the numerous measurements presented in this paper and their assistance is greatly appreciated.

The influence of the pore structure on the electrical resistivity of the formation is of interest when it is desired to determine the usefulness of electrical-resistivity logs in a study of reservoir characteristics, particularly connate water. Hence, this is a discussion of the relation between the formation resistivity factor (defined as the resistivity of a rock 100 per cent brine-saturated, divided by the resistivity of the brine), and the permeability and porosity of the formation. The resistivity factor is an expression of the electrical conductivity of the pore structure. Furthermore, a correlation of the amounts of hydrocarbons present in porous rocks underground with fluid content in cores at the surface is attempted.

POROSITY, PERMEABILITY, AND RESISTIVITY FACTOR

These factors were measured on cores taken from each of several horizons. Figure 1 shows cores from the Paluxy sandstone at Chapel Hill, Texas. The

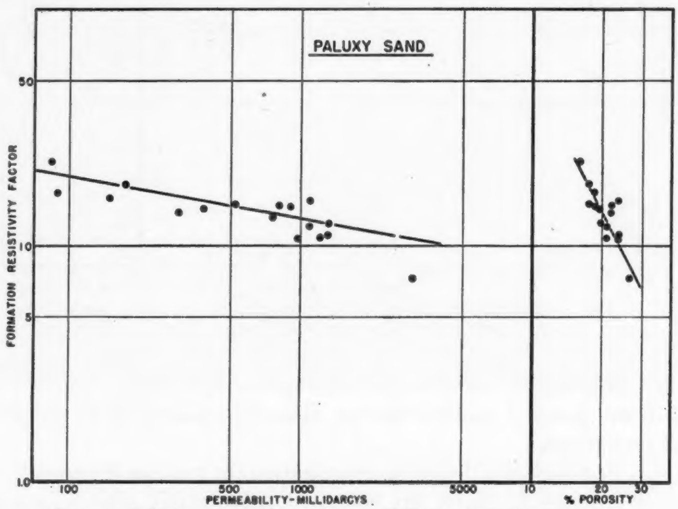


FIG. 1.—Relation of porosity and permeability to formation resistivity factor, Paluxy sandstone, Chapel Hill, Texas.

samples tested were fine-grained, sub-angular and uniform in grain size. The low-porosity samples were similar but very fine-grained and in general cemented to a greater extent. A photomicrograph of one of the more permeable samples is shown in Plate 1. Figure 2 shows the productive Devonian formation at Crosset, Texas. A photomicrograph of a core is also shown in Plate 1. Notice that it has an extremely fine texture, giving it a chalky or earthy appearance, yet hard. It is composed mainly of silica. However, varying percentages of calcium carbonate are present, particularly in the low-porosity samples.

In Figure 3 are plotted tests made on cores from the producing Smackover limestone at Magnolia, Arkansas. Photomicrographs of this oölitic limestone are given in Plate 1 to show the structure. Notice the coarse structure compared with the other types of rocks in Plate 1.

The Eocene Wilcox sandstone of Mercy, Texas, is shown in Figure 4 and photomicrographs are given in Plate 1. In contrast with the Paluxy, this sand-

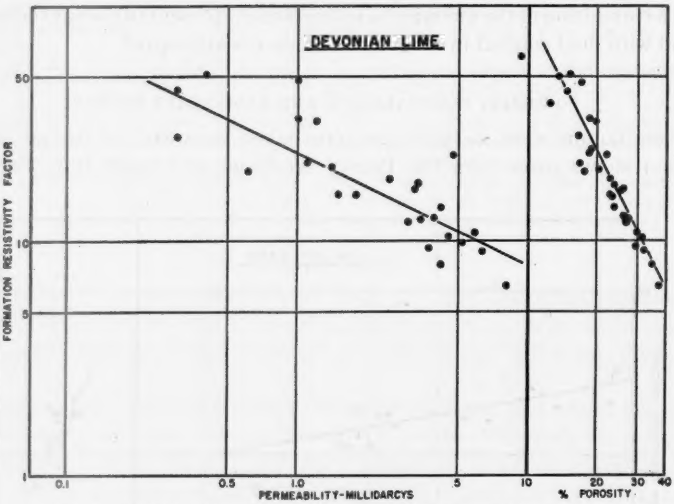


Fig. 2.—Relation of porosity and permeability to formation resistivity factor, Devonian limestone, Crosset, Texas.

stone is poorly sorted, particularly in the low-porosity range. Figure 5 shows a graph of the porosity plotted directly against permeability of the previously named formations.

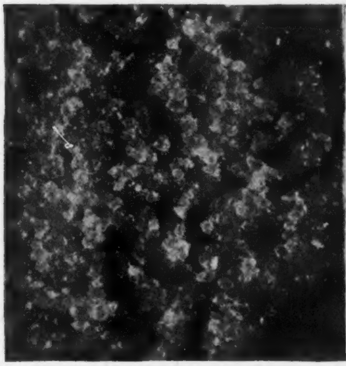
It may be noted that the points representing the relation of porosity, permeability, and resistivity factor are scattered considerably even within a given reservoir, yet definite trends are present particularly regarding the resistivity factor. For convenience of discussion, these trends are represented by lines in Figure 4-A and 5. Also shown are the averages of two other types of sandstone previously reported:[3] (1) Tertiary sandstones of the Gulf Coast and (2) Nacatoch sandstone at Bellevue, Bossier Parish, Louisiana.

The relation between the porosity and resistivity factor is significant because the average lines of resistivity factor *versus* porosity of consolidated rocks of different types are close together. Therefore, the porosity controls the resistivity

[3] G. E. Archie, "The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics," *Petroleum Development and Technology, 1942, Proc. Amer. Inst. Min. Met. Eng.*, Vol. 146.

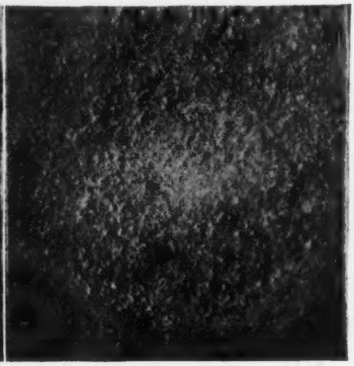
PHOTOMICROGRAPHS 15X

PALUXY SANDSTONE



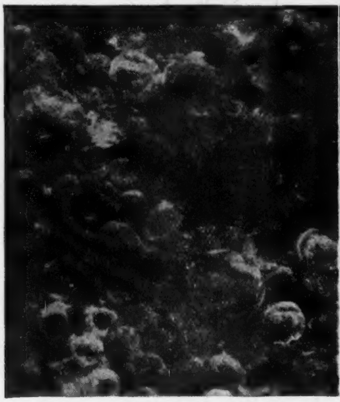
1048 MD. 26.5% POR.

DEVONIAN SILICEOUS LIME



16.4 MD. 35.9% POR.

SMACKOVER LIMESTONE, MAGNOLIA, ARK. 15X

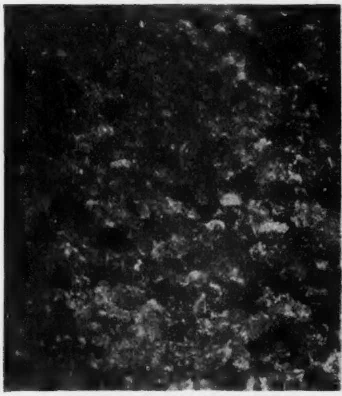


1350 MD. 18.5% POR.

103 MD. 13.1% POR.

0.9 MD. 7.0% POR.

WILCOX SANDSTONE, MERCY, TEXAS 15X



1240 MD. 23.1% POR.

101 MD. 20.9% POR.

18 MD. 12.4% POR.

PLATE I

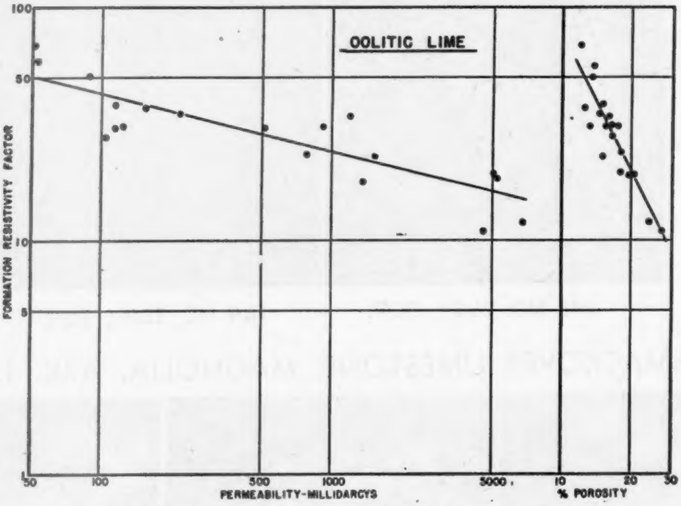


FIG. 3.—Relation of porosity and permeability to formation resistivity factor, Smackover limestone, Magnolia, Arkansas.

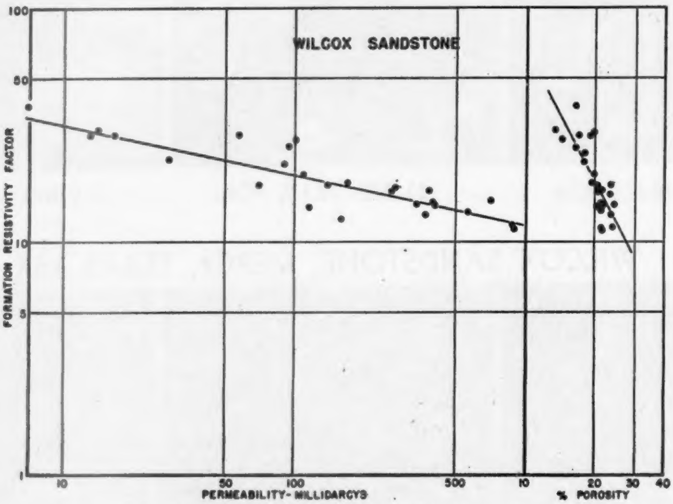


FIG. 4.—Relation of porosity and permeability to formation resistivity factor, Eocene Wilcox sandstone, Mercy, Texas.

factor, and the pore structure or type of rock does not have a great effect, particularly in consideration of the differences in structures involved as portrayed by the photomicrographs.

It is noteworthy that the manner in which the pores are interconnected (pore structure) does not greatly affect the electrical conductivity (see right-hand part of Figure 4-A), but has a large bearing on the air permeability (see Figure 5 and left part of Figure 4-A). Fluid flow and electrical flow are therefore not strictly analogous in this respect. In the first case, ions move in the fluid contained in the pores and in the latter case the entire fluid (or air) moves in the variously shaped pores of the formation.

It is believed that these data indicate a relationship of practical value between

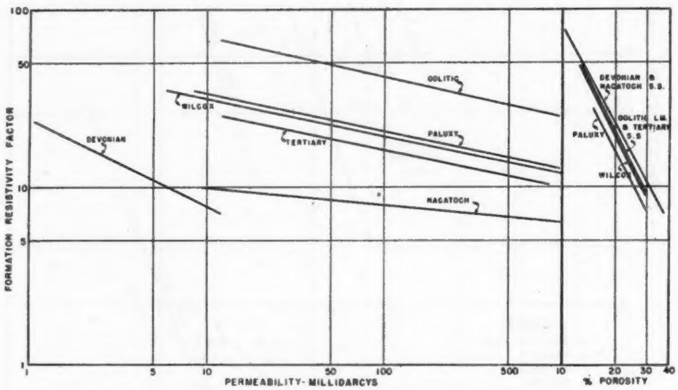


FIG. 4-A.—Showing average trends of various formations.

(1) porosity, (2) resistivity factor, and (3) type of formation. It is used in the calculation of connate water from the electrical log as described later.

The permeability for a given porosity varies markedly for different rocks, as well as for the same type of rock (Fig. 5). This would make a prediction of permeability from porosity very hazardous excepting possibly for an average of a thick formation having more or less uniform rock structure.

INTERPRETATION OF CORE-ANALYSIS DATA BY USE OF ELECTRICAL-RESISTIVITY CURVES

It has been found that cores having good permeability are invariably contaminated with drilling-fluid filtrate when ordinary water-base muds are used. If an oil-bearing zone is cored, the filtrate will enter the pores and displace the oil depleting the core in the same manner that a water drive will deplete an oil reservoir, leaving essentially only residual oil in the core. The residual oil in the core, at the bottom of the well, is under pressure and contains gas in solution. As

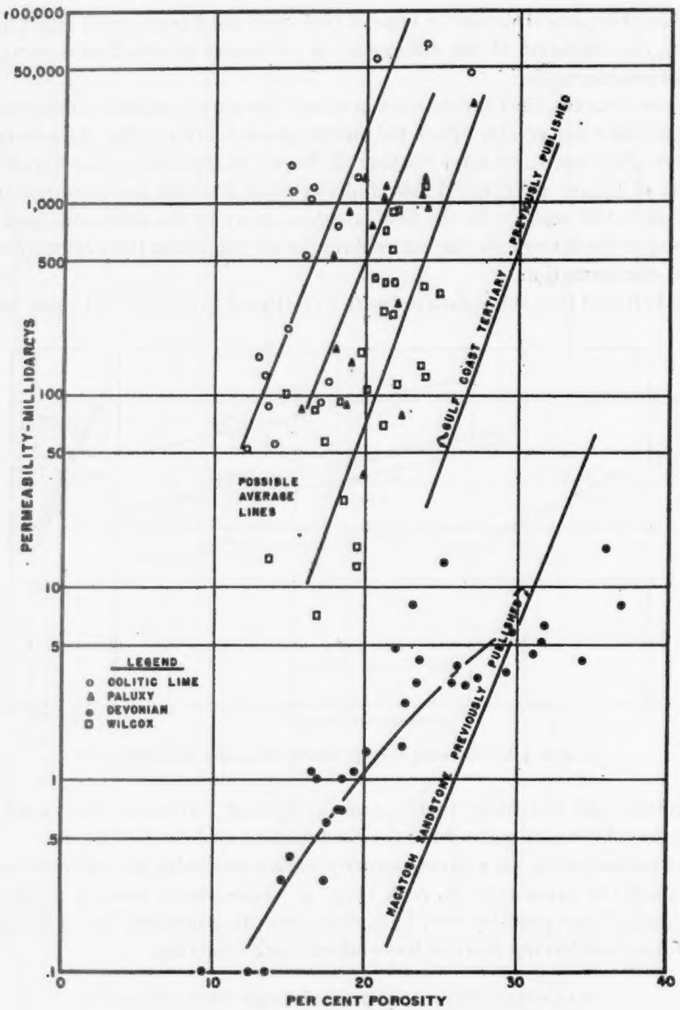


FIG. 5.—Permeability versus porosity for various formations.

the core is pulled to the surface, the gas comes out of solution with reduced pressure, forcing out mainly water. This stage may be compared with depletion by gas drive, except that mostly water rather than oil is expelled.

When the core reaches the surface, therefore, the residual oil will have shrunk by an amount dependent on the shrinkage factor of the particular oil and dis-

solved gas present in the formation, and, at the same time, part of the filtrate will have been displaced by gas.

The various factors that can affect the fluid remaining in cores at the well-head, therefore, are similar to the factors that are to be considered in water and gas drive, as well as the peculiar conditions connected with coring. The influence of gas-oil ratio, oil gravity, oil viscosity, bottom-hole temperature, the efficiency of displacing fluids by gas or water, and the mechanisms involved in coring have been discussed.[4] The relation of the fluids left in cores with the connate water

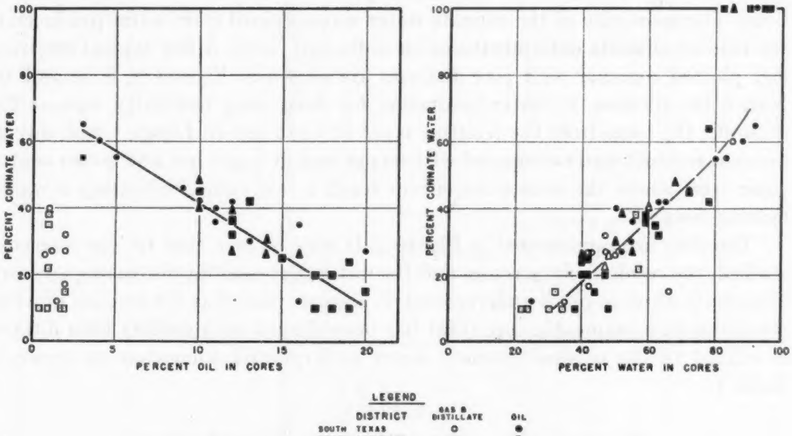


FIG. 6.—Comparison of oil and water in cores with connate water determined by electrical log, Gulf Coast fields.

present in the formations before they are disturbed by coring is considered next.

The connate-water content of a number of reservoirs in Texas and Louisiana was calculated from the electrical log and compared with the oil and water found in cores obtained from the same well. Oil-bearing reservoirs were taken in which the foregoing factors were approximately the same, that is, gas-oil ratios of the order of 300–800 cubic feet per barrel, gravity of oil about 37° API. depth greater

[4] C. H. Fancher, J. A. Lewis, and K. B. Barnes, *Pennsylvania State College Min. Indus. Exp. Sta. Bull.* 12 (1933).

H. C. Pyle and P. H. Jones, "Quantitative Determination of Connate-Water Content of Oil Sands," *A.P.I. Drilling and Production Practice, 1936.*

J. A. Lewis, and W. L. Horner, "Interstitial Water Saturation," *Geophysics* (October, 1936).

H. C. Pyle and J. E. Sherborne, "Core Analysis," *Petroleum Development and Technology, 1939, Proc. Amer. Inst. Min. Met. Eng.*, Vol. 132.

N. Johnston, "Core Analysis Interpretation," *Oil and Gas Jour.* (May 22, 1941).

S. E. Buckley and M. C. Leverett, "Mechanism of Fluid Displacement in Sands," *Petroleum Development and Technology, 1942, Proc. Amer. Inst. Min. Met. Eng.*, Vol. 146.

L. C. Uren, "Inspection and Analysis of Formation Samples," *Petrol. Eng.* (May, 1943), p. 70; bibliography.

than 5,000 feet, drilling muds with about a 10–15 cc. API. filter loss. All of the zones studied had permeabilities greater than about 30 millidarcys and were flushed with drilling-fluid filtrate as determined by chloride determination of the remaining water in the cores.

The comparison contains 64 consolidated sandstone zones in 9 districts; of these reservoirs, 21 zones were gas and gas-distillate, 37 were oil-bearing, 6 were water-bearing zones. A tabulation of all the intervals analyzed is appended.

The method of calculating connate water from the electrical log has been described.[5] The details of the calculations presented here are shown in the tabulations. The resistivity of the connate water was obtained from water produced in the field or chloride determinations on unflushed cores. A few typical electrical logs plotted together with core analyses are shown in Figures 7, 8, 9, and 10. Notice the increase in water saturation for decreasing resistivity values. For example, the cores from the resistive layer at 5,912 feet in Figure 7 had only 40 per cent residual water compared with 60 per cent at 5,922 feet and 90 per cent at 5,940 feet, where the resistivity curves reach a low value, indicating a water-bearing zone.

The data are summarized in Figure 6. It may be seen that for the reservoirs studied, the residual oil increases and the water decreases for decreasing amounts of connate water in place underground. It appears then that the amount of water remaining in a permeable core (that has been flushed with drilling fluid filtrate) is related to the original connate water underground somewhat as shown in Table I.

TABLE I

RELATION BETWEEN CONNATE WATER CONTENT OF RESERVOIR ROCKS AND FLUID CONTENT OF CORE SAMPLES

Original Connate Water of Reservoir (Percentage of Pore Space)	*Approximate Fluid Remaining in Permeable Cores (Percentage of Pore Space)*			
	Oil Reservoir		*Gas Reservoir*	
	% Oil	*% Water*	*% Oil*	*% Water*
60	4	85	—	85
40	10	65	—	65
25	15	50	0–2	50
10	20	30	0–2	30

It is interesting to note that the remaining water content of the cores taken from gas reservoirs is of the same order as that of cores taken from oil reservoirs containing the same amount of connate water. This offers a method of forecasting high gas-oil ratio wells from core analysis. For example, cores containing about 15 per cent residual oil and approximately 50 per cent residual water would indicate a normal gas-oil ratio well, approximately 500 cubic feet per barrel having 25 per cent connate water (if the foregoing conditions are assumed). However, for cores containing considerably less oil, for instance about 5 per cent, and the same residual water, the reservoir would be interpreted as containing a mixture of

[5] G. E. Archie, *op. cit.*

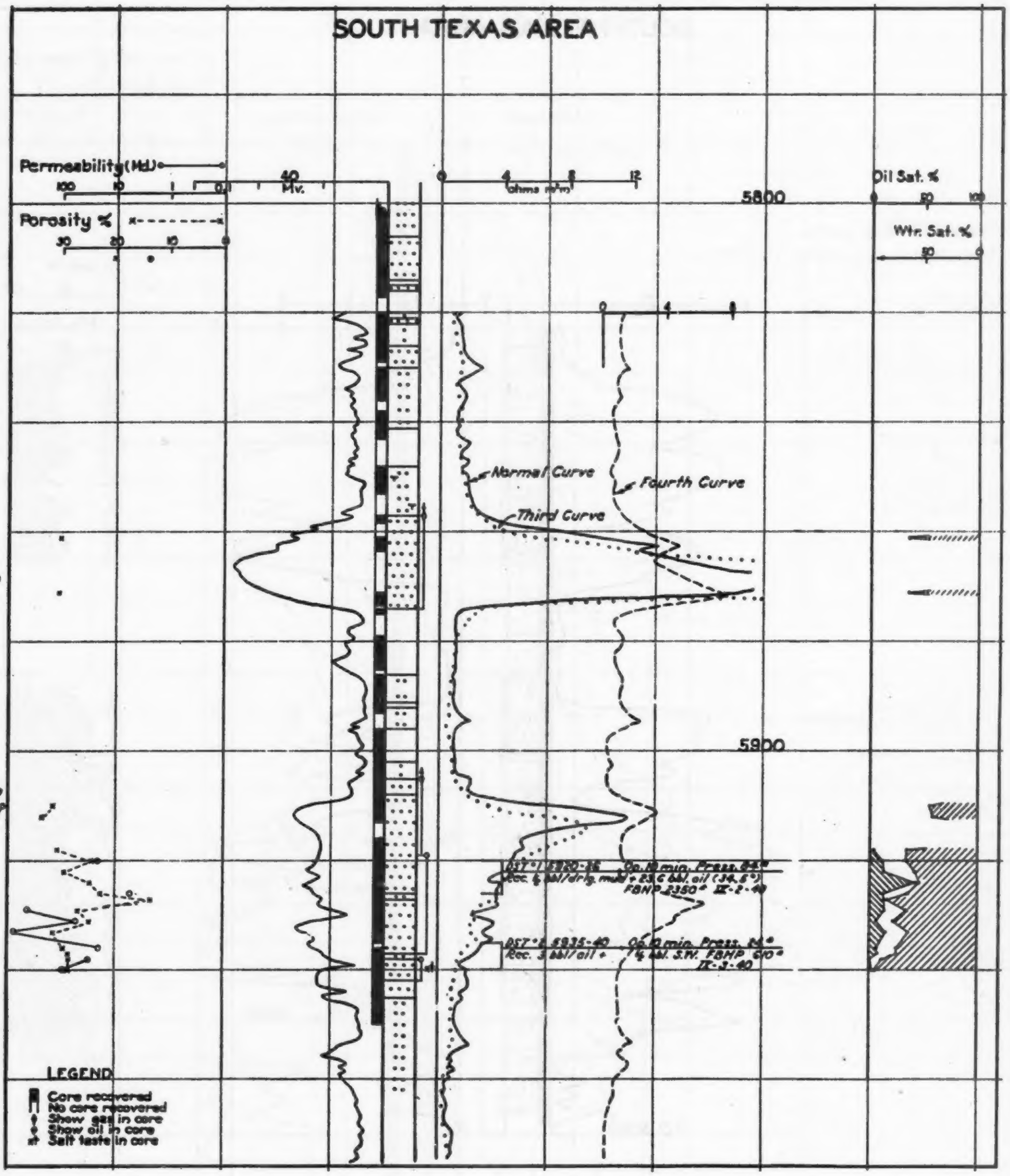


FIG. 7.—Electrical log and core graph, Frio sand, south Texas area.

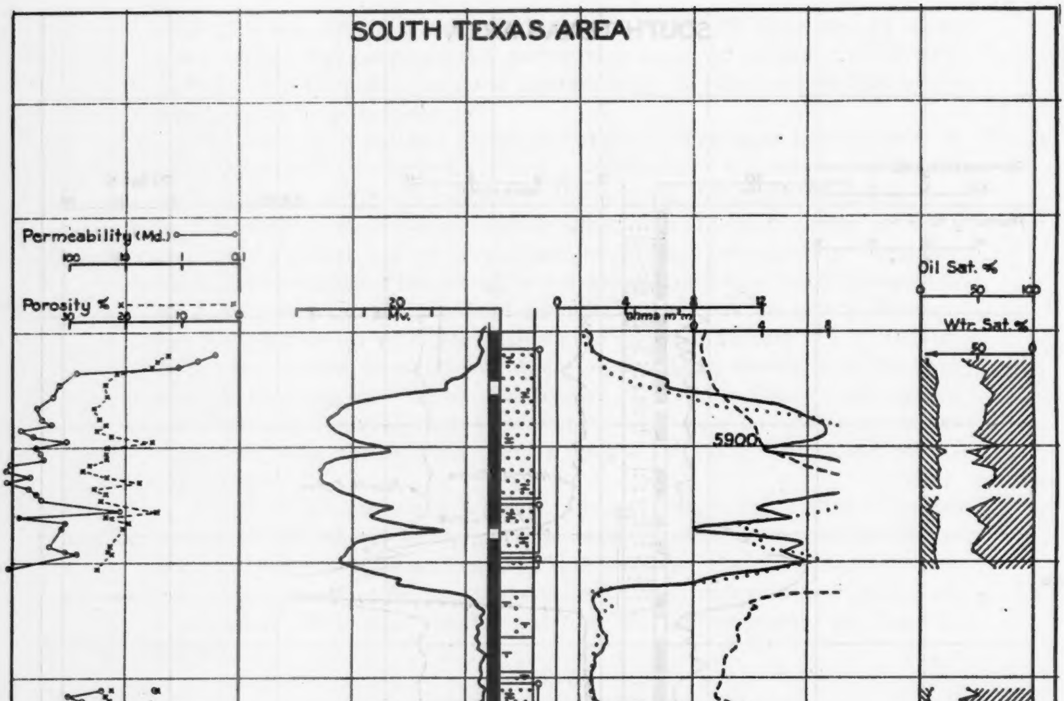


FIG. 8.—Electrical log and core graph, Frio sand, south Texas area.

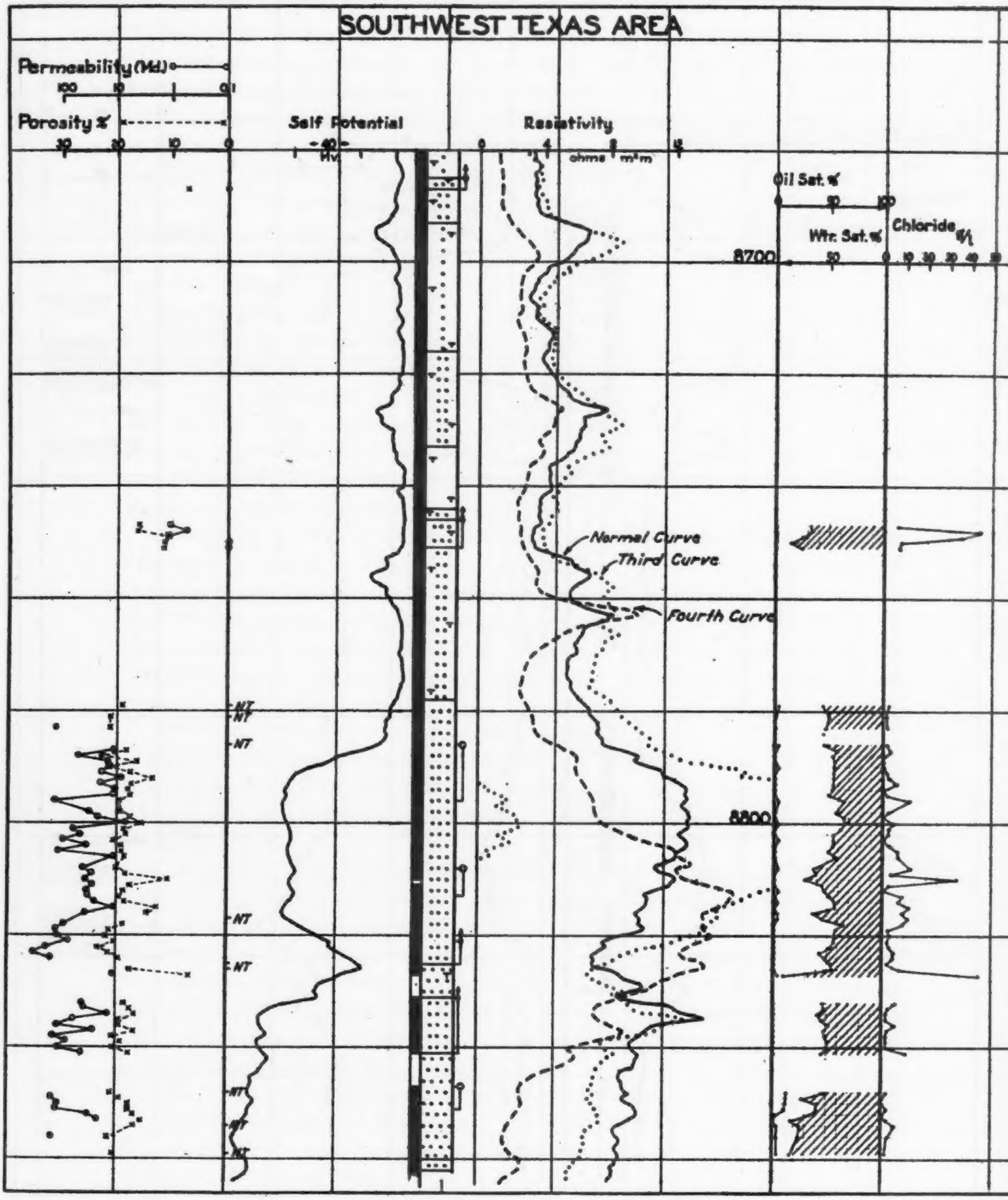


FIG. 9.—Electrical log and core graph, Eocene Wilcox, southwest Texas.

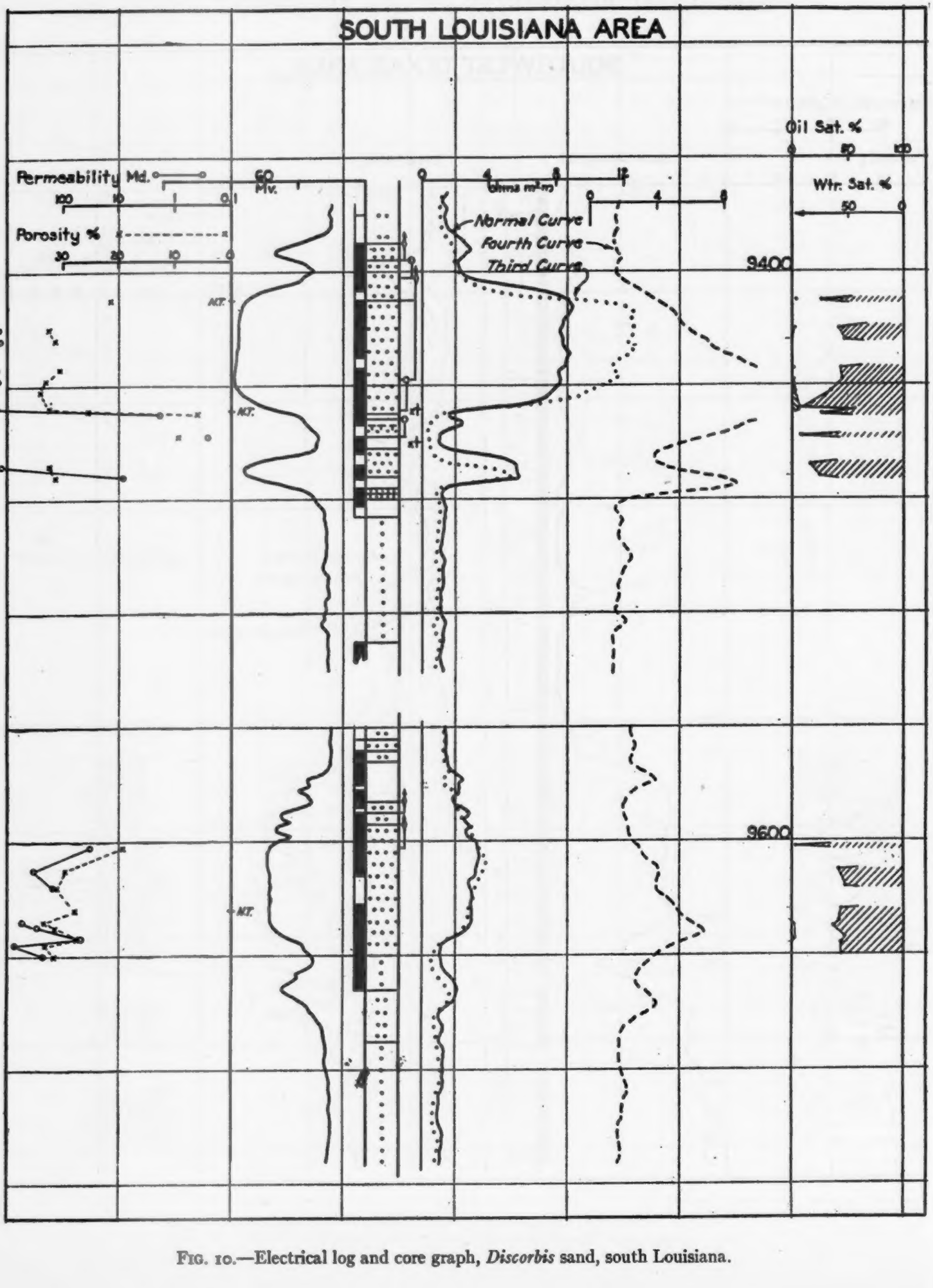


FIG. 10.—Electrical log and core graph, *Discorbis* sand, south Louisiana.

hydrocarbons with a high gas content, and 25 per cent connate water. These correlations appear to fit with, and may be explained by, the various mechanisms that take place on coring and withdrawing the core from the well. Empirical correlations for oil reservoirs other than those here considered, for example, lower-gravity crude, may be made in the same manner by use of the electrical log.

Highly permeable sands, high water-loss muds, or slow drilling may cause more than average flushing. That is, the flushing action may pass through the initial stage and into the subordinate stage as described by Buckley and Leverett.[6] When the chloride content of the water in a core is low, it is certain that at least one pore volume of filtrate has passed through the core, and the oil content is reduced to *nearly* its residual amount, or that the initial flooding stage has taken place. However, the flushing may have continued to the subordinate stage and the oil reduced *slightly* more.

An example of more than average flushing of highly permeable sands is the first layer listed in Table II, at 5,858–5,874 feet, also shown in Figure 7. As the connate water of this layer is calculated at 15 per cent, the cores normally should contain about 40 per cent residual water. Yet the cores recovered, measuring 10,000 millidarcys, contained 66 per cent residual water.

If water saturation in a core is used for estimating connate water, particular care must be exercised at the well. The core must be taken from the core barrel immediately on its arrival at the well head, the mud cake scraped off, and the core either analyzed or put in a sealed container until it can be analyzed. If the core is allowed to remain in the core barrel after it reaches the surface, it will take take up water from the mud that is in the barrel. If it is allowed to remain exposed to the air, water will evaporate.

Experience has indicated that three or preferably more individual analyses of a permeable layer are necessary to attempt an interpretation. The fluid content of individual cores should not vary greatly from the average of the group. It is found that shale breaks or tight streaks cause irregular flushing of the permeable sands near them.

Contaminated cores from beds already depleted by water drive will have fluid contents similar to cores from producing beds. Encroaching water will have reduced the oil in the pores to the residual amount and further flushing by mud filtrate will not reduce this value appreciably. Also, formations are found that have been depleted by nature before the first well was drilled. For instance, suppose a hydrocarbon trap is present, and, after oil has accumulated, the structure shifts and a trap is no longer present. The oil is then displaced by water and all but residual oil is flushed from the old trap.

The method is not applicable to unflushed or only partly contaminated cores, for in this case complete flushing or "water flooding" has not taken place and depletion of the core by gas expansion is the main process undergone by the core. A measurement of water saturation in an unflushed core of a producing formation

[6] *Op. cit.*

TABLE II

FLUID LEFT IN CORES VS. ORIGINAL CONNATE WATER
SOUTH TEXAS

Core Analysis								Electric Log Analysis					Production Data	
Depth (Feet)	No. of Samples Analyzed	Approx. Permeability	Porosity	% Oil	% Water	Chloride Content of Water g./l.**	Type of Sand	Form. Resist. Factor	Resist. of Connate Water*	Calc. Resist. of 100% Water Sand*	Resist. of Sand from Log*	Connate Water %	Gas-Oil Ratio	Gravity Oil
5,858–74	2	10,000	30	0	66	—	Con. Sd.	9	.07	0.63	30	15	Gas horizon	
5,909–14	2	2,000	32	0	43	—	"	7	.07	0.49	10	22	Gas cap	
5,918–26	4	—	25	12	63	—	"	13	.07	0.91	5.0	42	312	35.1
5,926–38	5	±300	27	9	72	—	"	11	.07	0.77	3.5	46	312	35.1
6,378–90	7	±200	24	0	85	—	"	14	.05	0.70	1.7	60	Gas cap	
6,390–06	6	±100	27	3	92	—	"	11	.05	0.55	1.3	65	60′ oil D.S.T. (2 min.)	
6,410–15	3	—	30	0	92	—	"	9	.05	0.45	0.6	100	Below oil-water contact	
5,906–14	5	1,000	30	0.8	50	—	"	9	.07	0.63	9	26	Gas cap	
5,914–24	5	1,000	25–30	16	62	—	"	9	.07	0.63	5	35	428	35.6
5,924–40	10	±100	20–25	4	88	—	"	14	.07	0.98	2.5	60	428	35.6
5,922–34	5	400	27	20	52	—	"	11	.07	0.77	10	27	456	35.3
5,938–44	4	100	27	5	83	—	"	11	.07	0.77	2.5	55		
6,386–02	7	±100	26	3	80	—	"	12	.05	0.60	2.0	55	316	41
9,685–9710	14	500	27	13	55	—	"	10	.07	0.70	8	30	760	38
9,661–70	9	400	30	1.0	60	2.5	"	9	.07	0.63	4	40	Gas-distillate zone	
10,123–37	12	100	28	10	65	—	"	10	.07	0.70	4	42	850	37
10,050–55	5	13,000	29	1.5	35	—	"	8	.07	0.56	35	12	Gas-distillate zone	
10,055–61	6	13,000	28	16	25	—	"	8	.07	0.56	35	12	—	37
10,109–18	7	100	27	11	55	—	"	11	.07	0.77	6	36	600	37
10,612–48	27	1,000	28	1.2	42	—	"	9	.07	0.63	8	27	Gas zone	
9,610–20	10	300	27	2.0	47	—	"	10	.07	0.70	9	27	Gas-distillate zone	
9,630–42	7	300	27	2.0	47	—	"	10	.07	0.70	7	32	Gas-distillate zone	
10,020–30	6	4,000	26	2.0	42	—	"	10	.07	0.70	25	17	Gas-distillate zone	
10,080–100	14	100	25	11	50	—	"	13	.07	0.91	6	40		
SOUTHWEST TEXAS														
8,024–38	11	30	21	1	48	4.0	Hard	20	.05	1.00	14	26	Gas cap	
8,082–88	3	100	22	0	47	3.0	"	18	.05	0.90	18	22	Gas cap	
8,122–36	11	100	22	12	52	10.0	"	17	.05	0.85	6	38	—	
8,136–47	9	100	19	10	68	12.0	"	22	.05	1.10	5	48	600	37.8
5,227–34	6	400	27	10	60	—	Con. Sd.	12	.1	1.20	7	40	D.S.T. oil	39.6
5,794–01	6	300	23	0	85	<5.0	"	15	.1	1.50	2	100		
5,886–96	6	250	24	14	42	<5.0	"	14	.1	1.40	20	26	D.S.T. oil	39.8
5,896–09	12	700	24	16	40	<5.0	"	14	.1	1.40	20	26	D.S.T. oil	39.8
5,909–21	8	—	23	14	50	<5.0	"	15	.1	1.50	18	30	D.S.T. oil	39.8
5,965–87	17	700	25	12	55	<5.0	"	13	.1	1.30	18	27	550	41.7

TABLE II—(*continued*)

	Core Analysis							Electric Log Analysis					Production Data	
Depth (Feet)	*No. of Samples Analyzed*	*Approx. Permeability*	*Porosity*	*% Oil*	*% Water*	*Chloride Content of Water g./l.***	*Type of Sand*	*Form. Resist. Factor*	*Resist. of Connate Water**	*Calc. Resist. of 100% Water Sand**	*Resist. of Sand from Log**	*Connate Water %*	*Gas-Oil Ratio*	*Gravity Oil*
							SOUTH LOUISIANA							
9,401–21	5	3,500	32	1.0	57	1.0	Con. Sd.	8	.06	0.48	9	22	Gas cap	
9,527–30	3	400	28	1.0	62	—	"	12	.06	0.72	6	35		
9,605–20	8	400	30	1.0	56	—	"	10	.06	0.60	4	38	Gas-distillate zone	
10,101–10	5	500	31	12	63	—	"	9	.06	0.54	5	32	800	37.2
8,832–36	4	1,300	29	15	42	1.0	"	9	.06	0.54	8	25	700	37.1
8,787–94	7	1,000	32	19	40	—	"	8	.06	0.48	8	24		
8,858–68	4	600	32	12	59	—	"	9	.06	0.54	4	36	700	37.4
8,881–85	4	50	29	0	78	—	"	10	.06	0.60	1.5	64	Open to prod. with above interval	
9,350–68	7	100	28	0	96	—	Cons. Sh. Sd.	—	—	—	—	100%	Water-bearing	
9,450–60	5	2,200	31	0	82	—	Cons. Sd.	—	—	—	—	100%	Water-bearing	
9,560–77	5	30	20	0	94	—	Cons. Sd., Sh.	—	—	—	—	100%	Water-bearing	
9,645–53	8	1,000	31	1.0	59	—	Cons. Sd.	9	.06	0.54	3.5	38	Gas-distillate	
8,812–20	4	2,000	31	18	40	—	"	9	.06	0.54	>15	<20	D.S.T. oil	
11,445–55	5	3,000	28	2	30	—	"	10	.03	0.30	25	10	Gas cap	
11,459–64	2	3,200	27	18	38	—	"	10	.03	0.30	30	10	—	39
11,404–30	5	1,000	25	1	34	—	"	13	.03	0.39	>30	<10		
11,483–91	4	2,500	25	17	42	—	"	12	.03	0.36	>10	<20	700	35
11,495–00	5	2,500	27	20	44	—	"	12	.03	0.36	>15	<15	700	35
7,309–25	4	5,000	30	1.8	22	—	Loose Cons. Sd.	8	.04	0.32	28	10		
7,547–66	6	2,000	29	0.5	33	—	Cons. Sd.	9	.04	0.36	30	10		
7,426–50	7	5,000	33	17	24	—	Loose Cons. Sd.	7	.04	0.28	40	<10		
7,474–7516	9	1,200	29	18	47	—	Calcareous Sd.	9	.04	0.36	10	20	450	39
8,242–45	3	60	23	13	78	—	Cons. Sd. Shale	14	.04	0.56	3.0	42		
8,257–77	5	2,200	27	19	48	—	Cons. Sand	10	.04	0.40	35	10		
8,285–97	3	45	24	10	72	—	"	13	.04	0.52	2.5	45		
9,548–65	8	2,500	34	0	90	—	"	7	.03	0.21	0.25	100	Water-bearing	
8,130–42	4	3,000	27	2	32	—	"	12	.03	0.36	>20	<15	Gas-distillate	

* In meter-ohms at bottom-hole temperature.
** Values less than 1.0 are not reported.

would, of course, give the connate water direct. However, it must be remembered that unflushed cores do not always give the connate water direct, for connate water as well as oil may have been forced out of the core by expanding gas when water *in situ* is relatively high. Only a small percentage of gas (free or in solution with oil underground) is necessary to expel a surprising amount of fluid.

SUMMARY

A correlation of various rock characteristics and fluid left in cores has been made with electrical-resistivity values, the results of which are summarized as follows.

1. A relation between porosity and formation resistivity factor of permeable rocks exists which does not change greatly for different rock structure. This is in contrast to a relation between porosity and permeability which does change appreciably for different rock structures.

2. A relation exists, for the sandstone beds chosen, between the water content in a flushed core and the connate water underground.

3. The residual oil saturation of cores is related to connate water *in situ*, but is dependent on other factors also, for example, gas-oil ratio. If it is possible to obtain the connate water from water saturation in a core, then the residual oil content of a core would be useful in predicting these other factors.

The use to which core-analysis data can be put depends greatly on the collection of many data because of the various variables involved. Although it has been possible to cover only a few of these, it is hoped that this paper will stimulate further interest and publication on this important subject.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 367-374, 1 FIG.

GEOLOGICAL NOTES

SIGNIFICANCE OF FISH REMAINS IN RECENT DEPOSITS OFF COAST OF SOUTHERN CALIFORNIA[1]

LORE DAVID[2]
Pasadena, California

An abundance of fossil fish remains, especially well preserved scales, has been found in marine sedimentary formations of the Pacific Coast of northern America. Such materials occur from northern Washington to the Imperial Valley, and range in age from Upper Cretaceous to Pliocene. To establish the facts of ecology as applied to fossil faunas, it seems important to investigate the abundance and distribution of fish remains in Recent deposits. As yet nothing is known of these occurrences, and no attempt has been made to interpret the ecological conditions of the marine Cretaceous and Tertiary of the Pacific Coast in the light of a knowledge of comparable Recent fish-scale assemblages.

Considerable information is available about the distribution of living fish faunas in different parts of the oceanic realm as a result of investigations during the past several decades. This knowledge has been utilized in work on the fossils. In view of available information, the fossil deposits of the Pacific Coast are regarded as having accumulated in fairly deep water; there is evidence of the presence of assemblages of the deep neritic zone and of others that extend downward to abyssal zones. Shallow-water deposits are rare. In such instances, only single scales are occasionally found. There is an especially strong similarity between the abundant bathypelagic faunas of upper Miocene age in California and those Recent marine faunas off the West Coast which, with the help of statistical information, give evidence of an existence under similar ecological conditions.[3] However, in the latter case, completely preserved fishes such as *Lampanyctus*, *Cyclothone*, *Chauliodus*, and *Bathylagus* furnish the best evidence.

It should be remembered, however, that in the instance of assemblages from the geological past, the recognition of specific kinds of fish on the basis of scales is reached without benefit of the entire fish—so commonly available in the study of modern piscine faunas.

When identification of fossil fish assemblages is based only on scales, the faunas are generally found to be composed of a more restricted number of forms than those that constitute the fish population living in the ocean at the present time, in similar habitats that might have assembled the scale deposits.

[1] Manuscript received, November 29, 1946.

[2] Division of Geological Sciences, California Institute of Technology. Contribution No. 398. The writer is indebted to Chester Stock for assistance in the preparation of this report.

[3] Lore David, *Bull. Geol. Soc. America*, Vol. 55 (1944), pp. 1467, 1468).

In this connection sea-bottom samples of Recent deposits taken by Manley L. Natland during the period of 1926–1933 in the Catalina Channel, off the coast of southern California, were examined. Those that contained significant fish remains are discussed here under three groups. These samples were collected originally for a study of the distribution of Foraminifera in Recent sediments. Most of the sediments represent small grab samples, and show no fish remains of significance. It should be indicated also that many samples were taken in shallow water, and fish remains occur in them only rarely.

GROUP 1

Drag samples were taken in the Catalina Channel with a small wire drag. This drag moved over considerable distances and the intended catch was primarily one of Mollusca. The samples of sediments contained mollusks, generally small or fragmentary, numerous worm tubes, brittle stars, corals, sponge spicules and other Metazoa, but comparatively few Foraminifera and of little variety.

Sample No. 163: Taken on July 29, 1933, off Balboa in Catalina Channel; location 33° 34′ 30″ N. Lat. and 117° 53′ 55″ W. Long., at a depth of 630 feet (192 meters).

Fish remains present: Numerous unidentified bones and vertebrae; *Sardinops coerulea*, the pilchard, 12 scales, 5 smaller fragments; *Pneumatophorus diego*, the mackerel, 1 scale; *Ahtherinops californica*, smelt, 1 scale; undetermined Sciaenid, croaker, 1 scale.

Sample No. 144: Catalina Channel; location 33° 35′ 45″ N. Lat. and 118° 16′ 20″ W. Long., at a depth of 770 feet (231 meters). Bottom temperature 8.8°C.

Fish remains present: *Sardinops coerulea*, 32 scales—about two thirds of these large scales are in a more or less fragmentary state of preservation; 2 ventral scutes of the same species; *Pneumatophorus diego*, 3 scales; *Salmo* sp., 1 scale; *Sebastodes* sp., rockcod, 2 scales; *?Sebastodes* sps., 5 scales; *Merluccius productus*, hake, 8 scales.

Sample No. 139: Catalina Channel; location 33° 39′ 25″ N. Lat. and 118° 16′ 49″ W. Long., at a depth of 825 feet (247.5 meters).

Fish remains present: Numerous unidentified bones and vertebrae; *Sardinops coerulea*, 30 to 35 scales, in part fragmentary; *Pneumatophoros diego*, 2 scales; *Merluccius productus*, 2 scales; Sciaenid fish, 1 or 2 species, 5 scales; *Sebastodes* sp., 2 scales.

GROUP 2

Samples 152 A and B were taken on March 4, 1933, in the Catalina Channel evidently in a deep submarine canyon.

Sample No. 152 A: Location 33° 39′ 00″ N. Lat. and 118° 18′ 25″ W. Long., at a depth of 518 meters. Bottom temperature 6.2°C.

Fish remains present: Bones and vertebrae common; rare fish teeth; *Sardinops coerulea*, 3 scales and 20 or more small fragments; *Merluccius productus*, 3 scale fragments; *Pneumatophorus diego*, 2 scales; undetermined Myctophidae, large scaled species, 2 scales; small-scaled species, 2 scales.

Sample No. 152 B: Location 33° 38′ 40″ N. Lat. and 118° 18′ 35″ W. Long., at a depth of 1,840 feet (approximately 561 meters). Bottom temperature 6.0°C.

Fish remains present: Common bones and vertebrae; *Sardinops coerulea*, 1 scale, 10 or more

smaller fragments; *Merluccius productus*, 1 scale; *Pneumatophorus diego*, 1 scale; undetermined Myctophidae, large-scaled species, 1 scale, small-scaled species, 1 scale. The quantity of material studied of this locality was less than that from 152 A, which accounts for the difference in numbers of scales found.

Sample No. 137: Collected on August 8, 1932; location 33° 33′ 17″ N. Lat. and 118° 15′ 40″ W. Long. Taken near position of sample 152 but at shallower depth (472 meters). Bottom temperature 6.4°C.

Fish remains present: Few bones and vertebrae; slender curved fish teeth, 4; Clupeid scale fragments, 5 or more; *Pneumatophorus diego*, 2 scales; *Merluccius productus*, 1 scale. Fish remains present only in moderate abundance.

GROUP 3

Sample No. 109: Location 33° 26′ 40″ N. Lat. and 118° 19′ 50″ W. Long. Taken near deepest part of Catalina Channel at a depth of 2,860 feet (approximately 758 meters).

Fish remains present: Numerous bone fragments and vertebrae; fish teeth; small fragments of Clupeid scales, evidently of the pilchard *Sardinops* 15 to 20; *Merluccius productus*, 1 small fragment showing center of scale; Gadoidea, cod fishes, *?Bathygadus* sp., 2 scales, fragmentary; Myctophoidea lantern fishes, large-scaled species, 4 scales; undetermined Iniomi, 2 species, 4 scales and 2 scales.

The differences between the ecological conditions which existed during accumulation of the samples of these groups is clearly evident. Group 1 has samples from approximately 190 to 250 meters in depth—all scales found belong to the neritic fauna, for example, smelts, mackerels, pilchards, croakers, rockcods, and also the hake. They give a fairly good representation of this habitat. Group 2, from approximately 470 to 560 meters in depth, presents scales of forms of neritic origin as well as of bathyal faunas—pilchards, mackerels, and hakes are again characteristic—but lantern-fish scales, as well as some long curved fish teeth, are also present. In group 3 the well preserved scales of sample 109 from a depth of 758 meters are those of bathyal fish, lantern fishes, *Bathygadus*, and some undetermined thin scales of bathyal groups of the Iniomi.

CONCLUSIONS

The few available samples as here described lead to the following conclusions.

1. Well preserved fish remains are present in Recent sediments.

2. Sampling the ocean floor with a canvas drag appears to be an efficient way to collect fish remains.

3 Skeletal material and scales of the more commonly occurring fish are only found at certain localities; these vary in depth from 192 to 758 meters (the latter being the deepest area from which samples were available).

4. The assemblages clearly indicate that they accumulated under different conditions.

5. Similarity to Tertiary fossil assemblages known from southern California is apparent.[4]

6. The fish remains in Recent sediments show greater similarity to those of

[4] Lore David, *Carnegie Inst. Contrib. Paleon.*, Pub. 551, Papers III, IV, V (1946).

the California Pliocene or uppermost Miocene (Delmontian) than to any other fossil faunas known. In the Pliocene, however, as stated before, such materials are rare in comparison with those found in sediments of earlier ages. The types commonly found and identifiable on the basis of this kind of material are gadoids, lantern fishes, and two Clupeid fishes, known only by scales, one of which is similar to *Ganolytes*, while the other is more like a small sardine. In addition there are *Merluccius* and *Bathygadus*, a Sciaenid, possibly *Cynoscion*, as well as a smelt, *Atherinopsis*, and others.[5]

[5] Lore David in "Report of the Committee on Marine Ecology as Related to Paleontology 1944–1945," Harry S. Ladd, Chairman, *Natl. Research Council Div. Geol. Geog.*, Rept. 5 (1945).

TEMPERATURE CORRECTIONS IN ALTIMETER SURVEYING[1]

JAMES K. ROGERS[2]
San Antonio, Texas

The necessity of making corrections for temperature in many cases of barometric surveying and the general procedure for making such corrections were set forth by Rich[3] in 1934, as well as by Hill[4] in 1929 and by Lahee[5] in 1931. Since accurate work requires that such corrections be made except in cases where the relief is small or where the temperature is near 50°F., the amount of computation involved is considerable for traverses which include large numbers of readings.

In order to simplify the procedure for correcting a traverse for temperature, the writer has made use of a chart differing somewhat in design from that used by Rich.[6] In this chart, elevations are plotted along the vertical axis and temperatures along the horizontal axis. A sliding scale (Fig. 1), is used for the barometric readings; corrections can be made directly to any appropriate datum by setting the sliding scale with that datum opposite the horizontal center-line of the graph. As in Rich's method, temperature corrections for all readings of a traverse are made with respect to a single datum. Once this datum has been selected and the sliding scale set for it, the correction for each barometric reading is found by starting at the corresponding elevation on the sliding scale and going to the right to a point under the temperature reading to be used. This point will generally fall between two of the heavy curved lines; the figure printed between the curved lines is the amount of the correction. If positive, it is added to the observed barometric reading; if negative, it is subtracted. If the point falls on the heavy

[1] Manuscript received, December 26, 1946.

[2] Geologist, Arkansas Fuel Oil Company. The writer expresses his appreciation to John L. Rich and L. W. Clark, who read the manuscript and offered helpful suggestions.

[3] John L. Rich, "Corrections for Temperature in Barometric Surveying," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 1 (January, 1934), pp. 133–38.

[4] Raymond A. Hill, *Preliminary Survey Procedure*, American Paulin System, Inc., Los Angeles (1929).

[5] Frederic H. Lahee, *Field Geology*, 3rd ed. (1931), pp. 457–67.

[6] John L. Rich, *op. cit.*, p. 134.

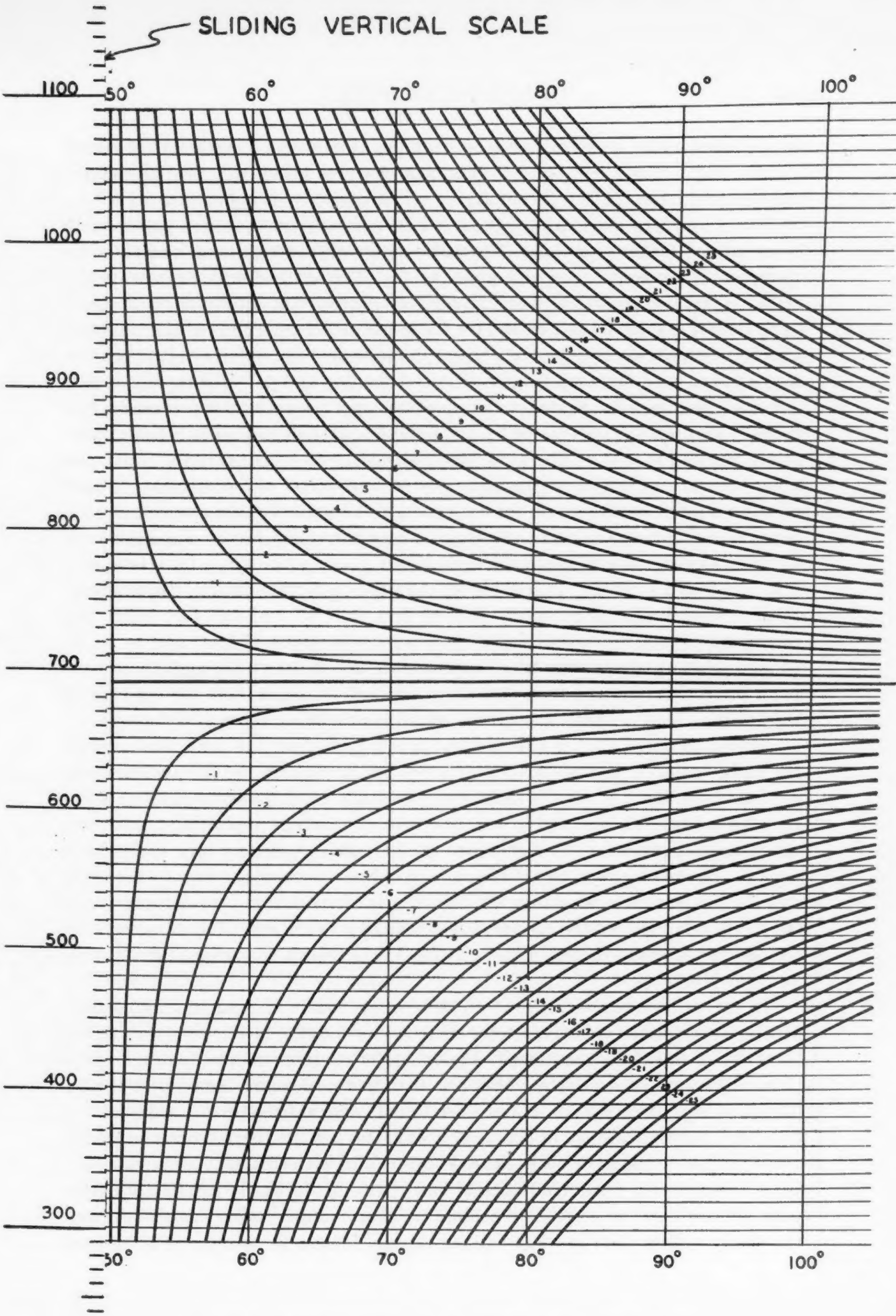


FIG. 1.—Chart for temperature correction of altimeter readings.

line between minus 2 and minus 3, for example, it indicates a correction of minus $2\frac{1}{2}$ feet, and minus 2 feet is used. (For temperarures below 50°, the 60° column may be used for 40°, the 65° column for 35°, *et cetera*, by using inverse signs.)

The graph was originally constructed on ordinary cross-section paper ruled in inches and tenths of an inch. The scales used were: vertical, one inch equal to 50 feet, and horizontal, one inch equal to 5°F. The vertical scale represents the vertical difference, positive or negative, in feet, between an altimeter reading and some elevation selected as a datum for the temperature correction of the traverse. The horizontal scale as shown on the graph represents the difference between the temperature used for correcting an altimeter reading and 50°. It is readily apparent that the curves are those for the equations $xy=1$, $xy=3$, $xy=5$, *et cetera*, and they are most easily constructed by using these equations and substituting appropriate values for x or y. The same result would come from assuming numerous temperatures and altimeter readings above and below the correction datum, plotting a point on the graph for each pair, and computing the amount of each temperature correction, using the approximate correction factor of 0.2 per cent (of the difference of elevation) for each degree above 50°F. Thus, for a temperature of 65° and a reading 50 feet higher than the correction datum, the temperature correction is approximately plus $1\frac{1}{2}$ feet, for 75° and 150 feet below the correction datum, the correction is approximately minus $7\frac{1}{2}$ feet, and so on. If enough pairs of values were used, and smooth curves drawn through those having a correction of plus $\frac{1}{2}$ foot, and again similarly through those having plus $1\frac{1}{2}$ feet, plus $2\frac{1}{2}$ feet, *et cetera*, the curves would approximate those of the graph.

It will be noted that in this method it is not necessary to take into account the daily variation in atmospheric pressure before making the temperature correction. In ordinary work it is satisfactory to make all of the temperature corrections for a day's traverse and to use the corrected readings in plotting the barometric pressure curve for the day. Since the barometric pressure falls throughout most of the working day, elevations as read in the afternoon are usually too high, and the temperature correction will be too great for readings considerably above the temperature correction datum, but this error is taken care of by the daily correction curve, where there is a tie-in at a point of known elevation at sufficiently frequent intervals.

In the writer's experience, the greatest single source of error in making temperature corrections comes from the difficulty of measuring temperatures representative of the atmosphere itself. Thermometer readings in direct sunlight or in proximity to objects radiating heat are of course misleading. Since time is at a premium in altimeter work, it has been found more satisfactory to take four or five temperature readings in course of a day, leaving the thermometer in shade, away from the ground or other heated objects and with sufficient air circulation, than to attempt a greater number of hasty readings. A fairly satisfactory temperature reading can be made by holding the thermometer several inches out from the shady side of the car while driving rapidly for a mile or more. The time of

each temperature reading is noted, and a temperature curve plotted for the day's traverse, as explained by Rich.

In regions of high relief it has been pointed out by L. W. Clark[7] that corrections made by using the temperature reading at a given station for correcting the altimeter reading at that station do not always agree with those obtained by the standard Paulin procedure, where the average of temperature readings at two successive stations are used for making the temperature correction. From a theoretical standpoint, it would appear to be most accurate to reduce each temperature reading, at whatever elevation it be taken, to a corresponding temperature at the level of the correction datum, but unless several thousand feet of relief are involved in a traverse, it is probably neither necessary nor desirable to do this. In areas of moderate to high relief, however, where a temperature reading is taken along with each altimeter reading, it may be found desirable to use an average of two or three successive temperature readings in making the temperature correction for each station.

Although each person who uses an altimeter will develop his own system of note-taking, the following is suggested as an arrangement and heading of columns on a notebook page.

Location of Reading	*Odometer Reading*	*Temp.*	*Time*	*Barom. Reading*	*Temp. Corr.* (+ or −)	*Rdg. Corr. for Temp.*	*Barom. Corr.* (+ or −)	*Corr. Elev.*
(Oct. 20. Temp. Corr. to 750′)								
Altus, USBM 537	919.9	63°	10:36	537	−5	532	+5	537 BM
Rd. cor. top hill N. of Altus	20.72	63°	10:44	803	+1	804	+1	805
Rd. cor., SE. cor. Sec. 34	23.61	65°	11:02	876	+4	880	−8	872

Since all readings of each day's traverse can be as readily corrected for temperature to one elevation as another by use of the chart, several other choices are open for a correction datum. It is possible to use: (1) a datum plane below the valley bottoms of the district, as recommended by Rich, or (2) the elevation of the first bench mark used, or the one to be used most in course of the survey, or (3) any arbitrary datum plane (or that of a chosen bench mark) approximately midway between highest and lowest elevations likely to be encountered. This last choice has the advantage of a smaller maximum interval of air column for which to make the temperature correction.

The general procedure for altimeter surveying has been covered by Rich, Lahee, and others, and the sequence of note-taking and correcting may be that indicated by the headings of columns suggested for a notebook page. Usually, the

[7] L. W. Clark, personal communication, September, 1946.

steps in correcting the traverse are as follows: (1) plotting the temperature-time graph for the day, (2) setting the sliding vertical scale of the graph with the chosen temperature correction datum opposite the horizontal center-line of the graph, (3) for each barometric reading, starting at the corresponding point on the sliding vertical scale and going horizontally to the right to a point directly under the temperature (as read from the temperature graph) and reading the number and sign of the correction, given by the figure between the heavy lines, (4) entering the amount and sign of the correction in the proper column of the notebook page, (5) adding or subtracting the temperature correction and entering the result in the next column, (6) plotting the barometric correction curve, using the readings corrected for temperature and plotting those for known elevations (the curve is checked by plotting the slope indicated by repeated readings at an unknown point, and fitting this slope into the smooth curve of the entire graph), (7) finding an appropriate barometric correction for the time represented by each reading, and entering it in the next to the last column, with positive or negative sign; (8) subtracting or adding the barometric correction to the figure in column 7 to give the final reading for each unknown elevation; (9) comparing final readings for unknown points with check readings at the same points, either on the same traverse or on previous traverses.

GEOLOGICAL MAP OF NORTH AMERICA

Students of geology, particularly of North America, will recognize the importance of the recently published *Geological Map of North America* compiled by George W. Stose of the United States Geological Survey. This is the latest map showing the surface geology of the north part of the Western Hemisphere, from northern Alaska and Canada to Venezuela and Colombia. It is the only map published covering the areal geology of this large part of the earth since 1911. Two sheets printed in 19 colors, when mounted together, make a map about 76×55 inches. The scale is 1:5,000,000. Ninety map units are represented by color patterns, and each unit is explained by a detailed statement of formations. This striking work of lithographic skill in portrayal of a wealth of geologic information will make an impressive wall display in office, school, and library.

The *Geological Map of North America* is a completely new compilation financed by grants made by the Geological Society of America, the American Philosophical Society, and the American Association of Petroleum Geologists.

One copy of the map is well worth the price of $3.50, which may be sent to the Geological Society of America, 417 West 117th Street, New York 27, New York.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 375-394

RESEARCH

REPORT OF SUB-COMMITTEE ON RESERVOIR FLUIDS, RELATED CONSTITUENTS AND CONDITIONS[1]

G. C. GESTER,[2] Chairman
San Francisco, California

FOREWORD

The petroleum industry has, for several years, recognized a decline in rate of discovery of petroleum reserves in the United States. New fields have been more difficult to locate. The average size of the newly discovered fields has been decreasing, and the cost of finding has increased. No group within this industry is a better judge of these conditions than the membership of the American Association of Petroleum Geologists. The program of research in petroleum geology and allied sciences now in progress, under the auspices of that Association, is therefore both timely and appropriate. The primary objective of this program is to devise ways and means of discovering more oil.

The research committee of the A.A.P.G., under the leadership of Shepard W. Lowman, divided the broad field of investigation into several parts: stratigraphy, sedimentation, tectonics, and reservoir fluids. In outlining the needs of research in these various fields, the last topic "Reservoir Fluids" was later amplified to include closely related subjects under the revised title "Reservoir Fluids, Related Constituents and Conditions." The sub-committee assigned to this study made a survey of the field in an endeavor to ascertain not only what we know but, more particularly, to point out problems or topics which warrant further study or research.

Briefly summarized, the survey conducted by this sub-committee may be divided into the following subjects: (1) Formation waters, (2) Clay minerals, (3) Bore-hole logging, (4) Hydrocarbons, (5) Possible relations of bacteria to reservoir fluids.

Numerous pertinent questions relating to the various subjects presented themselves as the survey of the field progressed. Twenty-four of these queries are posed; some of them are more or less answered in the text of the report that follows. A number of these require further study, and the answers to some of them will come only through extensive research. Based on these pertinent questions, a general statement for five fundamental projects was evolved.

I. *Formation-waters project.*—Application of established and new techniques to a systematic program of analysis of formation waters in selected depositional basins in search of possible gradients or trends in water composition which may lead to new criteria for the discovery of oil.

II. *Hydrocarbons project.*—Endeavor to establish valid indices of the evolution of petroleum as determined by stratigraphic age, depth of burial, and original depositional environment. Application of determined indices as criteria of suggested hypotheses of the origin, migration, and accumulation of oil.

[1] This is the third of the "Final Reports on a Reconnaissance Survey of Research Needs in Petroleum Geology by the American Association of Petroleum Geologists Research Committee, 1945–1946." The first, "Report of Sub-Committee on Tectonics," by Philip B. King, was published in the *Bulletin*, Vol. 30, No. 12 (December, 1946), pp. 2040–63; the second, "Report of Sub-Committee on Stratigraphy and Sedimentation," by Marshall Kay, was published in Vol. 31, No. 1 (January, 1947), pp. 161–81.—S. W. Lowman, chairman, research committee.

[2] Consulting geologist, Standard Oil Company of California.

III. *Clay-minerals project.*—The identification, description, parameters, and behavior of clay minerals in sedimentary rocks as related to all types of well logging, core analyses, reservoir behavior, source beds of petroleum, base exchange, indices of sedimentational environment, and variations in permeability, porosity, and fluid saturation with burial and compaction.

IV. *Bore-hole logging.*—Determinaton of fundamental relations between rock characteristics for the use and application of bore-hole logging, thereby improving our knowledge of geological environments leading to the discovery and proper depletion of hydrocarbon reservoirs.

V. *Bacteria project.*—Investigation of the occurrence and activity of bacteria in reservoir fluids as an aid to the appraisal of the role of bacteria in the formation and transformation of petroleum hydrocarbons.

The next step in the Association's research program is to crystallize, from the general statements of fundamental projects, specific problems on which research should be conducted, and "blue-print" these projects in concise form. All projects of the various subcommittees will be coordinated in order to prevent duplication of effort and, at the same time, obtain the maximum efficiency in results.

INTRODUCTION

The primary objective in this A.A.P.G. research program is to devise ways and means of discovering more petroleum. This goal should be kept constantly in mind. There are two ways of discovering more petroleum: either improve our present exploration methods or develop new ones. Our A.A.P.G. research committee believes that this may be accomplished by means of cooperative research in petroleum geology and allied sciences.

This sub-committee's specific problem might be stated as a question, namely, "Are there any characteristics of reservoir fluids and related constituents which can be utilized as criteria in delineating specific areas in which there are probabilities of finding exploitable quantities of petroleum?"

Discussions at the Chicago meeting of the A.A.P.G. indicated the desirability of broadening the scope of this sub-committee's field of investigation to include clay minerals and various types of well-logging.

The results of this review may be summarized in a series of pertinent questions. Some of these questions and topics overlap the subjects of the other sub-committees, but a careful endeavor has been made to focus our efforts on reservoir fluids and closely related problems as the "theme song" of our investigations. It will be found that some of the questions are partly answered in this report on the basis of existing knowledge, while some are in process of investigation through current research, for example, A.P.I. Project 43, but on many others further research is clearly warranted.

PERTINENT QUESTIONS

1. Do accepted methods of analyzing formation waters recognize the presence of small concentrations of rare compounds that might be of prognostic importance?
2. Do formation waters carry substances that might act as catalysts in the genesis of petroleum? If so, what are these substances? Might they affect the process of migration and accumulation as well as the genesis of petroleum? Might they effect polymerization after formation of initial hydrocarbons?
3. To what extent are oil-field waters radioactive? Are the waters in the water-leg of an oil reservoir radioactive?
4. How far does formation water migrate from its initial position?
5. How can we account for observed concentrations of solids in formation water, that is, concentration far above that of sea water?
6. If salt water can be flushed by meteoric water from an aquifer originally containing salt water, oil, and gas, how can oil and gas remain?

7. What becomes of the saline water that is replaced by meteoric water when such replacement occurs?
8. Do oil-field waters contain fluorescent materials? If so, what are they and are they the same as the fluorescent materials in the oil? Are they present in the waters contained in the regional extension of the reservoir?
9. (a) Have we obtained all possible information concerning reservoir fluids encountered in dry holes drilled at considerable distances from producing fields?
   (b) Are we now making sufficiently critical analyses of fluids encountered in wells drilled for in-put purposes in secondary-recovery operations?
10. Are there significant differences between the physical and chemical characteristics of oil-field waters, gas-field waters, and formation waters not associated with petroleum?
   (a) How do oil-field waters differ in chemical composition from normal water of the same formations? ("normal" water refers to formation water not associated with petroleum.)
   (b) To what are any departures from this normal or regional composition due?
   (c) If certain constituents commonly found in waters off structure are not present in the waters in oil pools on structure, what has become of them?
   (d) What is the role of base exchange or of other effects on migration or evaporation around the bore hole in producing these oil-field waters?
11. (a) Is there a gradient of the change in the characteristics of formation water between the petroleum-bearing part of the reservoir and its regional extension as a water reservoir?
   (b) What are the variations in chemical composition of water from different depths in the reservoir?
   (c) How much of the original water is taken out as "water of crystallization"?
   (d) How does the saline content change if some of the water is taken out by crystallization?
12. Do changes in composition of reservoir water, due, for example, to influx of meteoric water produce changes in composition of associated oil?
13. (a) How many oils have strong polar characteristics? What are they?
   (b) To what extent is petroleum radioactive?
14. What oils have heavy metals in organic combinations?
15. Why do the chemical and physical characteristics of petroleum, occurring in rocks of the same age, often differ radically at various locations in the same basin?
   (a) What is the influence of the following on the gravity of oil
      (1) Depth, age, and character of producing formation?
      (2) Amount, age, and degree of folding?
16. What is the effect of chloride or other ions on petroleum genesis, migration and accumulation?
17. What are the original organic constituents which make up source beds? What portion of the original organic endowment of a formation remains in place to-day?
18. Does genesis of petroleum occur in a single operation or is it a more or less continuous process of alteration and conversion, beginning during the deposit of sediments with their organic content and continuing through the period of migration and accumulation?
19. Does petroleum migrate in (a) the gaseous phase, (b) the liquid phase, (c) as an emulsion, or (d) in some form of water-soluble proto-petroleum?
20. How far does petroleum migrate from its source beds?
21. Why does petroleum occur in commercial quantities in one region but not in commercial quantities in another near-by region wherein conditions for its formation and collection seem to be as favorable as in the first region?
22. What effect do clay minerals have on the genesis of petroleum and the later characteristics of reservoir fluids? Do clay minerals act as catalysts?
23. Are bacteria indigenous to oil-field waters, gas-field waters, and formation waters not associated with petroleum? If so:
   (a) What effect might bacterial action have on:
      (1) Composition of reservoir fluids?
      (2) Transformation and migration of petroleum?
24. How can the interpretation of electric, radioactivity or fluoroscopic logs assist in the establishment of criteria to be used in locating petroleum?

Obviously some of the qualities and functions of reservoir fluids are closely related to, dependent on, or influenced by, chemical composition and physical makeup of reservoir rocks, including: permeabilities, pressures, temperatures porosities; influence of geological structures or traps; geologic age; time of diastrophic action; time of origin and accumulation of petroleum; *et cetera.* These and many other characteristics are related to or overlap the subjects of stratigraphy, sedimentation, and tectonics.

ACKNOWLEDGMENTS

The sub-committee's survey and review of reservoir fluids included, in addition to an analysis of pertinent literature, correspondence, and consultation with numerous geologists not on the committee. The sub-committee is very grateful for the valuable assistance rendered in response to requests for ideas and suggestions. Particular mention should be made of the stimulating discussions at a meeting held in San Francisco, November 30, 1945, which was attended by Shepard W. Lowman, Lester E. Uren, J. May, F. Hudson, S. H. Gester, E. Adams, G. D. Louderback, and G. B. Moody. We are likewise very grateful for the ideas and encouragement resulting from a conference with K. C. Heald, Ben B. Cox, Gordon Gulley, and William Rand in the offices of the Gulf Company in Pittsburgh. Thanks are also due for the data and contributions submitted by Roy Morse and Paul Weaver on the subjects of oil-field waters and hydrocarbons and to Hubert Guyod for his proposed research project on electric logging. Last, but not least, we wish to express our thanks to G. B. Moody for his help in preparing and editing the report and to Miss Ann Brennan for compiling of a selected bibliography of subjects relating to reservoir fluids. Although this could not be made a part of this report it constituted a real contribution to the survey of the field.

WORK OF THE COMMITTEE

The A.A.P.G. research sub-committee, as finally formulated by our chairman, Shepard W. Lowman, and which was responsible for the section of the progress report of the research committee captioned "Reservoir Fluids," was composed as follows: R. F. Beers, W. R. Berger, R. N. Kolm, G. B. Moody, F. M. Van Tuyl, and G. C. Gester, *chairman*. The consultants to whom much thanks are due for their good advice and suggestions are: B. B. Cox, L. C. Case, and Claude E. ZoBell.

The progress report of this committee, dated January 15, 1946, was embodied as a chapter in the general progress report of the Association's research committee. The latter report, issued in mimeographed form, helped to serve as a background for the subject of geological research, one of the principal features of the Association's meetings at Chicago, April 1–5, 1946. The primary objective of the research meetings at Chicago was to summarize the surveys of the various fields on geological research outlined in the progress report, to select and develop therefrom important subjects on which further research was desirable as an aid to exploration and discovery of petroleum, and to develop plans for the formulation of research projects which the A.A.P.G. would sponsor.

Outlines for four major research projects were formulated by the sub-committee on reservoir fluids and, as a result of subsequent discussions, a fifth was added. These fundamental projects, as hereinafter summarized, were approved by the Association's main research committee with the recommendation that they form the nucleus from which a number of geological research projects could be blue-printed for approval and further action by the Association's executive committee.

One of the results of the Chicago meetings which directly affected the sub-committee on reservoir fluids was to broaden the scope of its field to include the closely related subjects of clay minerals and well logging. Much credit is due to R. F. Beers for his analysis of the important role played by clay minerals in the problems of origin, accumulation and production of petroleum.

The personnel of the sub-committee for the current year is as follows: R. F. Beers, L. C. Case, G. B. Moody, F. M. Van Tuyl, G. E. Archie, Claude E. ZoBell, and G. C. Gester, *chairman;* consultant, B. B. Cox.

Project leaders charged with the responsibilities of blue-printing the proposed projects have been appointed. These project leaders, or chairmen, and a summary of the major projects are as follows.

L. C. Case—I. Formation-waters project.—Application of established and new techniques to a systematic program of analysis of formation waters in selected depositional basins in search of possible gradients or trends in water composition which may lead to new criteria for the discovery of oil.

F. M. Van Tuyl—II. Hydrocarbons project.—An effort will be made to establish valid indices of the evolution of petroleum as determined by stratigraphic age, depth of burial, and original depositional environment. Accepted indices will be applied as criteria of suggested hypotheses of the origin, migration and, accumulation of oil.

R. F. Beers—III. Clay-minerals project.—The identification, description, parameters, and behavior of clay minerals in sedimentary rocks as related to all types of well logging, core analyses, reservoir behavior, source beds of petroleum, base exchange, indices of sedimentational environment, and variations in permeability, porosity, and fluid saturation with burial and compaction.

G. E. Archie—IV. Bore-hole logging.—Determination of fundamental relations between rock characteristics for the use and application of bore-hole logging, thereby improving our knowledge of geological environments leading to the discovery and proper depletion of hydrocarbon reservoirs.

Claude E. ZoBell—V. Bacteria project.—Investigation of the occurrence and activity of bacteria in reservoir fluids as an aid to the appraisal of the role of bacteria in the formation and transformation of petroleum hydrocarbons.

REVIEW OF FIELD—SUMMARY

Following the general line of attack outlined in S. W. Lowman's "Research in Geology" report of September 3, 1945, a survey of the field of reservoir fluids and related subjects was made. The first step in this review, or survey, was to prepare a selected bibliography of the more important publications relating to the subject. The review of published literature, combined with suggestions made by numerous geologists and engineers familiar with various phases of the problem, brought to our attention a number of interesting, pertinent topics on which further work may be warranted. It is from this list of topics that the twenty-four questions heretofore recorded in this report were prepared. The objective in this method of attack is to endeavor to find out what is not known rather than to prepare a treatise on what is common knowledge.

FORMATION WATERS

The importance of serious considerations of formation waters in relation to origin, accumulation, and production of petroleum was clearly apparent from the review of the pertinent literature. From the time of the drilling of Drake's well in 1859 to the present time, formation waters have presented a wide diversity of important problems, such as the separation of oil-bearing zones from water-carrying zones. This led to the important techniques of oil-well cementing and to the development of various instruments and methods now used in drilling to identify water, oil, and gas horizons. There is a whole series of problems relating to connate and interstitial waters. The role of formation waters in relation to origin, to compaction of sediments, and to migration and accumulation of petroleum present a gamut of perplexing problems. There are also problems relating to the chemical reactions between waters and reservoir rocks and other constituents and how this may change the characteristics of the waters. These, and the role of waters in primary and secondary recovery of oil, are some of the important problems.

It has been pointed out that the study of formation waters involves many problems physical, chemical, theoretical, and practical. There is an abundance of supporting evidence that the water found in reservoir rocks was either (a) entrapped in the rocks at the time of sedimentation (commonly termed "connate water"), or (b) water moved into its

present location from other rocks by forces of migration, and that in some instances a part, or all, of the latter may be meteoric water.

Connate water, as defined by Holmes, "is a term applied to waters buried with exogenetic formations and volcanic rocks and remaining stagnant except as they are liberated by diagenesis or metamorphism."

When we consider the movement of waters during the periods of compaction and diastrophism, and the pressures, temperatures, and chemical actions which may affect these waters during the passing of geological time, a wide field of speculation is opened up. Numerous observations have been made, data collected, and hypotheses evolved, but the questions may still be posed, "What diagenesis has taken place affecting the connate waters and are there any truly connate waters remaining in ancient sediments?"

Washburne and Lahee (1) point out that a solute content of the same number of parts per million total solids as that in recent sea water does not prove a connate water unless the composition of the water, that is, an actual chemical analysis of the water in the sedimentary rocks, is the same as the composition of the ancient water in which the rock was deposited; and even in this case the similarity of composition may be a coincidence.

It is known that the composition of the deep, subsurface waters is in general different from the sea water of to-day, and, in the same article, Washburne and Lahee state:

> Are present rock characteristics of deep waters related to topography or physiographic conditions of the time when the containing sediments were laid down, or are they related to structural features developed much later? Can they be used as indices of structural conditions favorable to oil accumulation? Water and oil, although having low coefficients of expansion, may nevertheless suffer compression under load and expansion under released pressure. Little has been done in studying how this important factor may affect the behavior of these fluids under increasing weight of accumulating sediments or under the removal of the load through erosion.

Commenting on the difference in chemical analyses of formation waters compared with recent ocean waters, Roland Beers in the Progress Report, Sub-committee Reservoir Fluids, points out that the

> agencies responsible for these changes are thought to be physical and chemical reactions between waters and between waters and rocks and undercurrent circulation of fluids. No proof of the origin or method of alteration of specific formation water is known.
>
> Observations have been made on the composition of formation waters and their relation to chemical and mineralogical constituents in rocks. These rocks may be the hosts where waters are now found or where they may have resided for a limited duration in the geologic past. Most of the published results on the subject are based on relationships determined by conventional chemical analyses. A few recent investigations employing radiometric techniques are inconclusive because of the scarcity of data.
>
> Geologists and petroleum engineers have made numerous measurements and analyses of the physical and chemical relationships of formation waters in reservoirs. The physical and chemical properties of reservoir fluids of all kinds, and their reaction upon each other has been studied, but much still remains to be done. API Projects Nos. 27 "Function of Waters in the Production of Oil from Reservoirs" and 37 "The Fundamentals of Hydrocarbon Behavior" have added new and valuable data. This is also true with respect to the physics and chemistry of clay minerals; surface energies, and their effect as catalysts; the correlation of catalytic cracking, principles with energy transformations in source beds and reservoir rocks.
>
> Water analyses have been employed for many years in problems of exploration for oil and gas. Changes in the concentration of chlorides, sulphates, total solids and the Ca:Mg ratio are indices of prognostic value. The same techniques are frequently applied to ground water not associated with petroleum. In this application they have no direct bearing on oil finding but indirectly they may reveal the presence of traps and thereby lead to discoveries of petroleum.
>
> No instances have been discovered where it is possible to say unequivocally that a certain body of formation water has a unique genetic relationship with a given sedimentary bed. Inferentially it is often remarked that a particular body of formation water must have been deposited with the sediments of that formation. If the permeability of this formation is, and always has been low, it is probable that much of the water trapped at the time of sedimentation still resides within the bed. There is no proof as to how much, if any, of the original water may have migrated to other formations. Inferentially it is stated that certain permeable sands have been flushed free of all or part of their

original water content by meteoric or other waters. The presence of underground streams is often observed from measurements of salinity under these circumstances. Still there have been extremely few instances where direct proof of these inferred circumstances can be established. Several theories have been advanced to account for the high salinity of formation waters (up to 220,000 p.p.m. total solids) compared with modern sea waters (38,000 p.p.m.). No proof of these theories has been established. Tripp has observed that evaporation of water by vertically migrating hydrocarbon gases cannot result in observed concentrations at depths in excess of one-quater the depth of the hydrocarbon deposit.

Based on their studies of oil field waters in the southern part of the West Texas Permian basin, Berger and Fash (2) postulated a definite relationship between the composition and concentration of these waters on the one hand, and the original structure and topography of the basin floor when the "Big lime" was deposited. It was noted that the total solids increase basinward, and are less on structural highs than in adjacent synclines. The constituents vary sufficiently to infer structural areas and possible production of oil. Additional studies may prove the relations that are to be anticipated in many basins, thereby giving the oil industry a new tool in oil exploration.

R. R. Morse has suggested:

(1) That a compilation and study be made of water analyses from certain widespread producing horizons, for example, the Wilcox of the Gulf Coast.

(NOTE:—This would be important in connection with a proper understanding of results under the project next described.)

(2) Geochemical study of oil field waters leading to a proper understanding of the real significance of their chemical composition—how do oil field waters differ in chemical composition from the normal water of these formations? To what are any departures from this normal or regional composition due? If certain components commonly found off structure are actually absent in the "connate waters" in oil fields, what becomes of them? What is the role of base exchange or of other effects in migration or evaporation around the bore hole in producing these oil field waters?

B. B. Cox makes the following suggestion regarding oil-field water problems.

I would like to see a review and summary of all the work that has been done on oil field waters. Some of the work Chase Palmer (3) did has, I believe, been overlooked, and he had some good ideas. My impression is that geologists by and large have been prone to consider oil field waters as more or less alike. In any event, little attention is paid by most operators to the effects of oil field waters. In some of your California fields, which are usually referred to as fresh water, there are very wide differences, differences which hold clays in place or disrupt them. In Michigan, Case has reported a well of extremely high salinity. Botset (4) and others have reported finding radium in all oil field waters where there are no sulphates or carbonates to precipitate the radium. Concentrations of radium in oil field waters are as much as 2,000 times that in the sea. Naphthenic acids are a known concentrate of some oil field waters, and their concentrations in California fields run a wide gamut.

Could there be a concentration gradient for the naphthenic acid content from the oil-bearing part of the reservoir to the water leg of the reservoir?

Paul Weaver calls attention to the fact that

For a long time it has been claimed that sulphates are low in oil field waters, although G. S. Richards was the first American author to accentuate this idea. It will be found that this observation was originally made by Hofer somewhere around 1875, as can be found by looking up the book written by Blumer some years ago. Is this really true in wtaer in oil fields and in the edge water immediately adjacent to them? And, if so, how far does this condition of low sulphates extend from an oil field?

L. C. Case submits the following.

Chemical and physical examinations of oil and water have shown a wide variety of characteristics which apparently have only remote relationships, if any at all. Further, all attempts to find a "common denominator" in oil field waters have failed utterly. Search for such a factor has been limited to assembling of water analyses and looking for common constituents or ratios. The water analyses invariably consist of the more common and easily determined elements or radicals. It occurs to me that the analysis of both oil and water must be approached from a different angle, if we are ever to succeed in correlating water characteristics with the occurrence of oil. There is apparently no fundamental basis for the assumption that contact with petroleum would change in any way the common water

constituents. Also, the peculiar conditions attendant to the genesis of oil would not logcially produce a peculiar type of water, judged by the common constituents. If follows that, if there exists any relationship, it will be found in some rare constituent which may occur only in minute amounts. Spectrographic analysis of inorganic compounds in oil field waters have been tried and found to have no particular advantage over usual methods. Investigation of organic compounds might prove more fruitful. Some oil field brines are reported to fluoresce under ultraviolet light but the reason for the fluorescence is not known. Naphthenic acid has been analyzed quantitatively in Venezuelan waters and possibly elsewhere. Other organic acids have been reported in the brines of Michigan and Louisiana. Identification of these organic acids and possibly similar compounds might lead to definite steps in the genesis of petroleum. There is also the possibility that the presence or absence of certain of these organic compounds in subsurface waters might furnish dependable evidence for the delineation of oil provinces.

CLAY MINERALS

It has previously been pointed out that some of the qualities and functions of reservoir fluids are related to and dependent upon the chemical composition and physical make-up of reservoir rocks and that some of these characteristics are closely related to or overlap the subject of sedimentation. This is particularly true of the characteristic composition and make-up of clay minerals. It is only in recent years that our attention has been focused on the important role that clay minerals may play in relation to origin, migration, accumulation, and production of petroleum. Some good work has been done by such authorities as Ralph E. Grim (5), R. A. Rowland (6), S. B. Hendricks (7), P. G. Nutting (8), Paul F. Kerr (9, 10), and C. S. Ross (10) on the identification, physical structure, and properties of clay minerals, that family of complex silicates which are covered by the genetic term "clays." Most of the research that has been done has been primarily for the ceramic and textile industries. Modern methods including the use of chemical analyses and dehydration curves, X-ray differential patterns and optical methods including use of the electron microscope have been employed but the review of literature leads to the conclusion that we know very little about the identification, properties, and functions of clay minerals in oil-field sediments.

An outline for the study of clay minerals was presented R. F. Beers at the Chicago A.A.P.G. meeting, and because of its close relationship to reservoir fluids it was considered reasonable to include it in this sub-committee program. We quote briefly from Beers' development of this subject.

Studies of sedimentation in relation to the occurrence of petroleum for the most part have been confined to sands and sandstones. Less attention has been devoted to aggregates of finer constituents, possibly because effective techniques are not so clearly deveoped. Effective analysis of the influence of sedimentation factors on the occurrence of petroleum has resulted in improved methods of development and production, but even in this area of research the influence of fine grained sediments is imperfectly understood.

In the origin and migration of petroleum the influence of fine grained sediments is profound. The permeability of reservoir and carrier-rocks is largely influenced by the particle size distribution of these rocks. The physical and chemical reaction of the rocks on the contained fluids must be great, yet little factual knowledge of this field has been brought to light.

Clay minerals are for our purposes the most significant constituents of the finer sediments to be investigated. Previous work in other fields has shown that shales possess a limited number of different mineral species. Some qualitative identification of species has been achieved and something is known of their behavior and properties. The subject has not been attacked, however, from the viewpoint of the petroleum geologist. Few workers in this field know, for example, the size and nature of the electric charge which accompanies each clay particle at the time of its dispersion. Little has been said of the surface energies which clay minerals may release for chemical and physical reactions under absorbed fluids.

The following is Beers' tentative outline of procedure.

1. Identification of the clay minerals in sedimentary rocks.
2. Description of the properties, parameters and behavior of these minerals in oil field environments as related to
   (a) Electric logging and radioactivity logging;

(b) Core analyses;
(c) Petroleum production and recovery, changes in permeability and surface tensions;
(d) Preparation of drilling fluids: the heaving shales;
(e) Source of beds of petroleum, the relation of clay minerals, organic matter and agencies of transformation;
(f) Catalytic action and surface energy of clay minerals, the reaction upon organic contents;
(g) Variation of permeability, porosity and fluid saturation with compaction and burial;
(h) The use of clay minerals in sedimentary rocks as indices of sedimentation environments.

BORE-HOLE LOGGING

The subject of bore-hole logging was not originally a part of the survey or review assigned to the sub-committee on reservoir fluids. Discussions at the research committee's April meetings in Chicago, however, emphasized the importance of conducting research on various problems relating to this subject, and it was decided to include bore-hole logging as a part of this committee's work. G. E. Archie has prepared for this report a statement on the subject of bore-hole logging as follows.

With deeper drilling, the mechanical difficulties and cost of obtaining cores are greatly increasing. This, together with the desire to log a hole to get desired information with the personal equation at a minimum (i.e., an individual's opinion of reservoir conditions based on visual inspection, measurement difficulties, *etc.*) makes research along these lines important.

Most logging devices do not record physical rock characteristics directly and the logs must be "interpreted." To do this, we must delve into other properties than those directly desired to solve our immediate problem and in this way our general knowledge of rock characteristics increases.

This is bound to lead to a better understanding of geology in general; sedimentation, tectonics, and environmental conditions as well as reservoir conditions, providing, of course, we discover the fundamental relations between the properties logged and the properties of rocks.

In the trend towards less and less coring and the use of more logging devices it must be kept in mind that no single device will yet give us lithology or type of rock. In geologic or reservoir studies this is paramount, for in all relations between rock characteristics, the type of rock is a common parameter. Therefore, the drill cutting log is a necessary adjunct to any other log. Also, any research on logging methods must include a study of how the types of rock are related to the property measured.

Research on bore-hole logging goes hand in hand with a particular branch of geologic and reservoir research, as reflected in the following suggested divisions of research.

I. Determine the fundamental relations between rock characteristics. Just how electricity flows through the pores of rock and the effect of different pore structures, just what causes a potential to exist at the sand-shale, and shale-mud contacts, neutron reaction, relation of radium content to sedimentation, investigations to see if shale sections slough off in a bore hole so as to indicate jointing dip of formations, to mention but a few that are currently being discussed by the industry. Consideration should be given to the measurement of other rock properties, not as yet measured in bore holes.

II. Improve our knowledge of conditions in given geological environments or horizons by making available and digesting pertinent data that will enable interpretation of the numerous logs available. Study all data in a given area, environment, or horizons as core, cuttings, electrical, radioactivity, caliper, *et cetera*. A few core data will go a long way to improve interpretation of electrical logs which are generally readily available. A tabulation for particular horizons of considerable areal extent of all porosity, permeability, water salinity, grain-size distribution of loose sands, geometry of grain arrangement, *etc.*, accompanied by logs and photomicrographs of the same interval, would enable logs be used to outline reservoir characteristics at other points in this horizon and would aid in interpretation of individual exploratory wells in this horizon. A study of all gamma ray logs in an area might throw light on sedimentary processes, geologic time, *etc.* The same may be said for neutron or caliper logs, particularly when fundamental factors and more advanced logging techniques are available.

III. Improve our knowledge of conditions existing in individual wells.

(A) The numerous measurements, which may be called central measurements, are the subject of this heading (IIIA). Interpretation of individual logs to obtain physical rock characteristics. This involves first a reasonable understanding of the fundamentals (I) above. More, however, is needed than the discovery of a relation. Charts and tables must be made up to show in detail how the variables are related in order that the general relation may be applied in practice. For instance, the formation resistivity factor has been shown to be related to total porosity and type of rock or pore structure. In order to use such a relation in practice numerous resistivity measurements must be made on different types of rocks.

(B) Interpretation of individual logs accounting for the more or less mechanical factors, as pres-

ence of the bore hole, thin layer effect, mud invasion, type of mud, *etc.* These effects must be deciphered before interpretation of rock characteristics can be attempted on a given well.

Specifically a research project to advance the whole art of logging, and therefore our general geological knowledge would include more than one part. Although these parts are all related, any one can be undertaken separately.

Part 1.

Fundamental research in the laboratory. For instance, investigate the electro- and physical-chemistry of shale and other rocks of low permeability. This will aid in understanding not only what variations in rock characteristics causes changes in self-potential, but what potentials may exist underground without the presence of the bore hole. The properties of shale are important in any study regarding reservoir traps, accumulation and migration of oil, sedimentation processes. The salinity and type of salts, for instance, may play an important part in the self-potential and resistivity and are important in reconstructing geological processes. If we knew more about these factors it is not inconceivable that the logs could be used for regional studies of geological processes to an unheard-of extent, particularly since electrical logs are run on so many wells.

Fundamental research is needed on nuclear physics, for instance, neutron reaction of formations (shales and other rocks) not only to determine what causes the variation on the neutron log but also to further study the rocks themselves.

The electrical conductivity of rock is not well understood. Just what effect does pore structure have on resulting resistivity and, conversely what type of pore structure exists in different rocks, particularly limestone?

Part 2.

A. Tabulation and publication of pertinent data of given environments or horizons. Particularly those data which directly aid in interpreting the various logs (suggested under II above), for many logs are already available in many individual, geologic environments or horizons. For example, the Eocene Wilcox of the Gulf Coast has been suggested as an interesting environment. The Devonian limestone of West Texas might be a combined limestone porosity and logging (electrical and radioactivity) research study.

B. Interpret the logs (electrical, radioactivity, *etc.*) in these environments based on the data thus establishing an overall picture of general geology as well as reservoir conditions likely to exist throughout the areal extent of the horizon or environment.

This should aid in interpreting specific conditions in exploratory wells in these given environments as well as promoting logging interpretation generally.

Part 3.

Improve interpretation of individual logs by laboratory models and measurements.

A. Measurement of formation resistivity factors of different types of logs and other measurements in which a relation is already known to exist but more data are needed for interpretation.

B. Use of models to study effect of bore hole, thin layers, mud, *etc.*, on electrical, neutron, *etc.*, measurements.

Part 4.

Drill cuttings and cores. Although the numbers of cores taken is decreasing, cores are still necessary and the interpretation of these analyses is still a major problem. Drill cuttings alwyas can be made available on notice and are probably "packed" with more information than all other logging methods can give at present. Although the art of cutting description is ood there is no doubt that many improvements can be made.

Electrical logging is discussed more specifically by H. Guyod, and we quote as follows.

Suggested Research Work for Improving the Usefulness of Electric Logs

The Logging Problems

A perfect logging method is one which would allow complete identification of all formations traversed by a bore hole and of their fluids. No such perfect method has been discovered as yet for the logging of rotary holes. Although, in theory, solid coring could provide the desired information, in practice this is usually not true because of the many cores which are not recovered. Furthermore, among those which are recovered, a number fail to provide accurate information on the fluid content

Because of its high cost, and also because of the limitations mentioned above, solid coring is only rarely used alone for the logging of rotary holes. The method which is preferably used at present is electrical logging, frequently supplemented by conventional or side wall cores and/or by other types of logs.

The wide acceptance of electrical logging does not mean that this method solves perfectly the problem mentioned, but rather that it processes a number of qualities which makes it generally preferable over the other available methods.

The three main problems which should be solved with a well log are:

1. geological correlations,
2. discovery of petroleum reservoirs,
3. estimation of reserves.

Although electric logs solve very well most correlation problems, they are not always successful for the discovery of petroleum or for the determination of certain reservoir characteristics because of their limitations.

LIMITATIONS OF ELECTRIC LOGS

In this memorandum the limitations of electric logs have been classified as intrinsic and non-intrinsic.

Intrinsic limitations. Electric logs, even when placed in the hands of a hypothetical perfectly efficient expert, fail to locate certain reservoirs—many shaley sands in particular—or to detect petroleum—oil in fractured limestone, for example. For an intelligent use of electric logs it is evidently necessary that these intrinsic limitations be exactly known.

Non-intrinsic limitations. The non-intrinsic limitations can be classified into two groups:

1. those which are due to insufficient knowledge of the basic facts underlying the properties measured,

2. those which are due to insufficient knowledge of the numerical values of the factors controlling the properties measured.

A typical example of the first group is given by the electrical potentials observed in bore holes. So little is known at present of their exact causes that the potential graph of an electric log is usually used in a rather crude manner. Another important example of this group is given by the electrical resistance of certain reservoirs.

A typical example of the second group is given by the electric resistance of sands and sandstones. Petroleum can be detected in these formations from electrical data only when an approximate value of the following properties is available:

Porosity of bed
Degree of cementation of grains
Connate water salinity

If little is known on these properties, the detection of petroleum is usually impossible.

Psychological limitations. In addition to the technical limitations discussed above, an important obstacle to the efficient use of the data given by an electric log is that the present interpretative techniques are not well accepted by most petroleum geologists because of their somewhat complicated aspect. The success of the methods depends upon the knowledge of the actual value of certain properties. Frequently this information is not immediately available, which discourages many of those who wish to make a rapid interpretation.

WHAT IS NEEDED

From the foregoing comments it is possible to summarize what is needed at present to improve the use of electric logs. These requirements have been classified under three different headings.

Fundamental Data. 1. Research is needed on bore hole potentials in order to elucidate the eauses of these potentials. Work along this line should reveal the main factors controlling the potential and their relative importance. Without this knowledge it is impossible to appreciate the exact possibilities and limitations of the potential graph.

2. Research is also needed on the resistivity of certain types of reservoirs, especially limestone in order to discover the exact relation existing between resistivity and the factors which control it, as has already been done for sands and sandstones.

3. More data are needed for translating apparent resistivity—i.e., log data—in terms of true resistivity—i.e., formation characteristics. At present data are available on only the simplest cases such as single beds situated in a thick and uniform medium. Similar data are necessary for more complex cases.

4. Finally, more data are needed for the estimation of porosity and permeability.

Statistical Data. Estimation of the petroleum saturation from electrical data is possible for many reservoirs provided the numerical value of certain factors is available. These numerical values vary from pool to pool, and sometimes from well to well in a single field. There is, however, a general trend in a given area which permits interpolating the data obtained for neighboring fields. A considerable amount of these data is in oil companies' files and is not confidential. It is certain that most companies would be willing to release it to help any project which would benefit the whole oil industry. Its compilation and publication in convenient form would be of considerable value for the interpretation of the logs of many wildcat wells and for other problems.

Educational Data. Electrical logging is the measurement of certain physical properties. These properties obey definite laws and are therefore susceptible of scientific interpretations when the pertinent data are available. This, unfortunately, is not generally recognized as yet. An important educational program is therefore needed. This would necessitate:

1. that the interpretative techniques be sponsored by an authoritative organization, such as the A.A.P.G. or the A.P.I., for example;
2. that enough data be available so that scientific interpretations will be possible in the majority of cases;
3. that these data be released in palatable form, i.e., in the form of charts and tables rather than in mathematical formulas.

CONCLUSION

Electric logs offer many attractive possibilities, some of them have not been tapped as yet. As long as the data mentioned above are not available to the oil industry, these possibilities cannot be fully developed. It seems that the importance of using efficiently a tool which is so widely accepted at present would justify the relatively small expenditure necessary for the completion of the research work outlined above.

PETROLEUM

Petroleum is the *sine qua non* of our quest. All other subdivisions of reservoir fluids as well as sedimentation, stratigraphy, structure, clay minerals, well logging, *et cetera*, all point toward our main objective, petroleum and the means of discovery of petroleum.

Under the caption of petroleum, the survey of the field brings to light a wealth of valuable literature. In addition to the published information there are unquestionably much pertinent data in the files of various oil companies. Discussions of the topical questions relating to petroleum (questions 13 to 21, inclusive) at the A.A.P.G. research meetings at Chicago, April 14, 1946, brought forth the opinion that answers or at least valuable data pertaining to some of those questions might be obtained from the files of oil companies who had conducted research relating to the particular subjects in question. Possibly this might be accomplished by the questionnaire method employed by F. M. Van Tuyl and Ben H. Parker in the preparation of their valuable contribution captioned "The Time of Origin and Accumulation of Petroleum." (11) In their introduction,the authors state:

> As the known pools of oil are depleted and the discovery rate of new fields is reduced, petroleum geology must offer more efficient methods for the location of additional accumulations if the development of reserves is to keep pace with consumption during the next few decades.
>
> It is a well-recognized fact that in many petroliferous provinces there are unproductive structures closely resembling nearby productive ones. The geologic history of a few of the barren areas appears to be somewhat different from those which carry oil or gas, but no variation has yet been found in many. Even though a different history is indicated, the cause of the lack of hydrocarbons in unproductives structures can only be guessed at.
>
> Obviously, a more critical study of such situations is necessary if much needless drilling is to be avoided. It would appear that in order to prospect intelligently for oil and gas in a given area more definite information should be obtained regarding their source, the time and conditions of their generation, and the mode and time of their accumulation into commercial pools. Adequate data may never be collected to answer satisfactorily the many baffling questions which arise in connection with such a study; but it is clear to those most familiar with the fundamentals involved that a critical examination of recent and near-recent sediments and the assembling and careful review of the multifarious data now available, as a result of extensive surface and subsurface geological investigations, should throw much light on the subject.

As a part of this sub-committee's survey of the field R. F. Beers submitted the following.

1. What do we know?

   It is assumed petroleum is derived from organic matter accumulated with marine sediments. The assumption is based on circumstantial evidence but seems reasonable. In the absence of the proof of a unique origin it is the basis of most of the analytical and experimental research on the problem. The sediments in which organic matter was deposited are known as *source beds*. These may or may not coincide with reservoir rocks from which fluids may be produced. In the latter case an explanation is required to account for the migration of fluids from source

beds to the place where they are ultimately discovered. The commonly accepted viewpoint is that petroleum accumulates in "traps," being isolated therein in concentrations which permit removal by wells located for that purpose. These concentrations are many times greater than those observed in source beds or migration channels. It is thus necessary to presuppose that an aggregating effect results from migration.

The ultimate oil "pool" represents concentration in a cubic volume the disseminated contents of many times that volume.

The agencies responsible for migration and accumulation are not known precisely. A number of hypotheses have been advanced, each supported with appropriate evidence by their sponsors. It is probable that combined efforts operate simultaneously or consecutively, depending largely upon specific local circumstances. Some of these factors are:

(a) Abundance of organic matter.
(b) Permeability to oil, gas and water of source beds, migration channels and reservoir rocks.
(c) Structural features of all rocks (involved).
(d) Availability of hydraulic and pressure energy and fluids for movement of petroleum.
(e) Existence of "traps" of all kinds which permit accumulation of petroleum in commercial quantities after segregation and migration. Probably all possible types of traps have now been recognized. These have been classified by W. B. Wilson (12) and the classification is generally accepted by geologists.
(f) The necessary and important impermeable seal which "caps" all known oil pools.

2. What important advances have been made in recent years, the results of which may not yet have been fully assimilated?

With new experimental techniques, API Project 43, now in progress, supplements a great amount of *a priori* research of earlier years. The evidence being gathered is largely on possible means of conversion of indigenous organic matter into petroleum hydrocarbons. Qualitative and quantitative relations must be established. The products of specific conversion processes must correspond with those found in petroleum. Material and energy balances must prevail if suggested means of conversion have made significant contributions to deposits of petroleum. The details required for the proof of a unique origin of petroleum are too great for application to specific pools at present.

No successful attempt has yet been made to correlate the radioactive and other trace elements in petroleum with the corresponding constituents in source beds, migration channels and reservoir rocks. The concept of "tracers" has been reported only once and that limited to the observation of the movement of fluids between wells by the use of dyes.

3. How is our knowledge being applied to finding oil?

It is doubtful if a precise knowledge of the many possible origins of oil would be of great value to the exploration geologist in his search for new deposits. Recognition of source beds is essential, however.

4. What obvious gaps are there in our knowledge or its application?

In a few special instances statements have been made that petroleum must have originated within a specific horizon. The conclusions reached in these cases are the result of eliminating all other possibilities and reducing the probability to a single place of origin. Such conclusions seem reasonable, yet they do not constitute direct proof of the identity of the formation in which the oil was produced.

Barton (13) has observed a number of empirical relationships among Gulf Coast crude oils: " . . . among crudes . . . of the same age, the API gravity . . . tends to increase and the . . . sulphur and carbon tend to decrease with depth. At the same depth . . . the same variations hold with increase in stratigraphic age. A law of variation of character with age and depth is suggested."

These observations form the basis for a theory of evolution of Gulf Coast crudes. "The respective ancestral crude oils of all the crude oils of the Gulf Coast were heavy naphthenic oils and . . . transformation of the character of crude oil has taken place in proportion to depth and to age. The transformation consists both in the decrease of the specific gravity of the individual fractions and the consequent change in the base from naphthenic toward paraffinic; and in the percentage content of the lower boiling fractions.

"The observed evolution of the Gulf Coast crude involves decrease of the ratio of carbon to hydrogen.

"The data are against cracking as the main reaction in that evolution. Pratt's methanation is regarded as the most plausible reaction to explain the evolution . . . .

"The statement of the law as induced from the variation of the crude oil from the Gulf Coast may be an incomplete, merely approximate statement of a more complicated law."

The theory outlined by Barton needs critical examination in its application to Gulf Coast crudes not previously studied. The theory applies to a limited number of fields outside the Gulf Coast. In many cases additional factors are known to apply. The entire subject of the

evolution of crude must be carefully studied in the light of established factors bearing on identification and alteration of oil. In this connection the work of Lucey and Sage (14), Rossini (15) and others on the determinative characteristics of crude oils must be applied. The subject seems of very great significance and not to be discarded because of the great loss of its prime exponent, Dr. Donald C. Barton.

5. What research is under way now, or is already projected, to fill these gaps?
   None known at present. [See Bibliography, Nos. 16–19 for Beers' references.]

Actual work on API Project 43, "Transformation of Organic Material into Petroleum Beds," was started July 1, 1942. A year and half had been spent in preliminary study in the formulation and financing of the project before work got under way. I believe we will all agree that Project 43 is producing interesting and valuable results. But is there not a corollary research project which should be carried in close cooperation with 43, namely: what geologic factors affect the characteristics of crude oil and what are the effects of each of these factors? Some excellent data on the subject of variation in physical properties are to be found in *Problems of Petroleum Geology*. Donald Barton, in his summary of these papers, ends with the paragraph:

> The study of the geologic variation of the character of crude oil offers an important and fertile field for research. Each variation in the character of crude oil must reflect some difference in source material or in geologic conditions to which the crude oil has been exposed. The studies to date indicate that many of the laws of that variation can be learned by careful analyses in which the character of crude oil is treated as a function of several variables and in which criteria more complete than merely the Baumé gravity and the qualitative character of the base are used for the character of the crude oil. Furthermore, the study offers an important methods of approach to the problem of the source of the oil. Source beds are suggested rather glibly in the geologic literature, but as a matter of fact there has been little analysis of the occurrence of crude oil sufficiently accurate to enable us to say definitely that this oil came from that formation. Not all organic material in sediments need *a priori* to be source material for petroleum; and the adjacent formation which is richest in organic material need not be the source material of a particular crude oil. Study of the geology of the variation of crude may show that a particular crude oil comes from a particular formation. The search for the source organic material may then be confined to that formation.

Here is a fertile field for research. First, to properly review, analyze, systematize, and coordinate all available data with the objective of outlining problems on which further work should be done, the final objective being to develop criteria, methods, or tools useful in exploration work in search for new oil.

B. B. Cox offers the following comments on this subject.

> On the subject of hydrocarbons much information has been collected and filed, if not published, but it still needs to be brought together and appraised. How many oils are there which have strong polar characteristics, and what are they? Why do some oil fields that have probably never been under critical phase conditions have lower gravity down-flank than crestward after correcting for gas solubility? What is bitumen doing in the bottom of the syncline east of the Quatar structure which will produce 34% crude? What oils have heavy minerals in their organic components? Gruse and Stevens (20) point out in the *Chemical Technology of Petroleum* that although crude contains many individual hydrocarbons, these hydrocarbons always fall into a few homologues, but the "tars" of Venezuela and Mesoptomia contain no distillate recoverable below high cracking temperatures. They are associated with dry gas analyzed as methane.

R. R. Morse has proposed the following problems.

> Collect and attempt to correlate comprehensive and reliable data on the original pressures and temperatures of gas condensate reservoirs, at saturation pressure, and chemical analyses of their contents (distillate and gas combined). Perry Olcott's project of obtaining an authoritative description of a number of such fields for a possible future A.A.P.G. volume is an excellent step in this direction.

Morse also suggests that a general study be made of the volume behavior of oil and gas mixtures as found in reservoirs at reservoir temperatures under various pressures. A pool of pertinent data from numerous oil fields scattered over the United States should afford valuable reference material and conclusions of benefit to the industry.

Accumulating evidence indicates that bacteria may play an important role, just how important we do not yet know, in the transformation of organic substances into petroleum, but there are almost certainly other important contributive factors involved in both genesis and migration.

We have two large areas, structural basins, both containing, let us say, 10,000 to 20,000 feet of sediments, shales and sands predominantly marine. In both cases the shales are classed as marine organic shales, in part fossiliferous. The reservoir rocks and structural conditions are well developed and ideal to form traps in both areas. There is no material difference in the carbon ratios. Geologically well located bore holes have been drilled to adequate depths for thorough testing in both areas. Numerous rich oil fields have been developed in area No. 1. In area No. 2, no commercial fields have been developed; only a small amount of oil and gas has been found in some of the wells. The "$64 question": Why is one area barren of oil fields whereas the other contains prolific oil fields? This question suggests other questions as follows.

Are the physical and chemical characteristics of the oils from the two districts the same? If not, what are the differences and to what may the differences be attributed?

Are there any substances present which might serve as catalysts in one area that are not present in the other area?

What differences are there in the chemical and physical characteristics of the subsurface waters?

Are the physical and chemical characteristics and amounts of organic material of the sediments the same in the two districts? If not, how do they vary?

Is the redox potential of the organic content of the strata in the two areas the same? If not, what are the differences?

In regard to the latter question, ZoBell reports that petroliferous sediments have relatively high reducing intensities and relatively low reducing capacities and that these properties may be characteristic of source beds of petroleum or producing beds. However, fresh- or brackish-water beds like the Green River shales, as well as Recent and Pleistocene sediments, would have to be ruled out (for the present at least) for the reason that data presently available indicate that some of these rocks are characterized as having low redox potentials.

This brings up another question commented upon by Ben B. Cox in a recent revision of his "Geological Fence": Why is there no evidence to prove that any petroleum has been formed since the Pliocene? To quote:

> Petroleum occurs in rocks of all ages from the Cambrian to the Pliocene, inclusive, but no evidence has been found to prove that any petroleum has been formed since the Pliocene, although sedimentation patterns and thicknesses in Pleistocene and Recent sediments are similar to those in Pliocene where petroleum has formed . . . . The apparent absence of formation of petroleum subsequent to the Pliocene must be explained in any study of the transformation of organic material into petroleum. . . . [And so Cox raises the questions of] whether bacteria do more than "Condition" organic material for transformation into petroleum and whether some other combination of processes and conditions does not complete the transformation.

The "carbon-ratio theory" promulgated by David White in 1915, is a tool of limited application in the search for oil. W. T. Thom, Jr. (21), states:

> In conclusion, the writer believes that it is much more reasonable to regard the metamorphic destruction of oil pools as having occurred progressively and gradually, rather than suddenly and at some closely defined inversion or conversion temperature or pressure having a definite, numerical, carbon-ratio expression.
>
> Practically the value of carbon ratios hinges upon their use in judging of the oil and gas possibilities of broad regions rather than in their use as a basis for predicting the presence or absence of oil in particular local areas. They do not afford sufficiently accurate or critical evidence to warrant the drawing of "deadline" limits to possible oil and gas occurrence.

There is a possibility that more exacting and detailed research would add to our better understanding of the carbon-ratio theory. The theory, however, probably does not warrant inclusion in the list of the more important research projects.

Professor V. C. Illings (22) states under caption of "The Migration of Oil,"

There can be no doubt that a still larger amount of oil and gas occurs as a more widespread but less concentrated impregnation of the denser rocks, the clays, marls, and limestone surrounding the reservoir rocks. It is generally agreed, however, that these denser rocks are, in the main, the media in which the oil originates, and their oil content is therefore not surprising.

A method of geochemical petroleum exploration frequently referred to as "soil analysis" is based on the hypothesis that products of petroleum are continually migrating upward through the superincumbent layers of rock and escaping to the atmosphere, leaving behind in the surface soil and subsoil minute quantities of gases, liqud hydrocarbons, and waxes. The liquid and gaseous hydrocarbons in passing upward through the earth are adsorbed on the individual grains. According to Eugene McDermott (23), "The methods of geochemical exploration permit the quantitative measurement of microscopic gas and oil seeps or mineralization phenomena."

Studies on bacteria as indicators of subterranean deposits of oil [says ZoBell] is a practical problem which merits extensive attention. The fossil remains of bacteria which oxidize hydrocarbons, exclusive of methane, may serve as indicators. However, these bacteria which actively oxidize hydrocarbons may give anomalous results in methods of "soil analysis" unless their activities are taken into consideration.

Serious questions have been raised as to the value of "soil analysis" as a reliable tool in petroleum exploration work. Apparently the methods employed have 'bugs" in them. If further research would show us what these "bugs" are, we might have a very valuable tool for aiding in the discovery of new oil.

If Professor Illings' statement is correct, or if there is justification for the hypothesis on which the principals of "soil analysis" are based, or if we accept the theory that many oil pools represent the acumulation of oil that originally was disseminated over a wide area and that later traversed beds of diverse texture containing reactive substances, is it not likely that the oil has undergone some recognizable changes?

Has it left fingerprints in any of the material through which it has passed; fingerprints which might serve to help identify source beds or the rocks through which petroleum has passed in the process of concentration in pools or have minute quantities of petroleum, after concentration in traps, seeped upward and left fingerprints on its upward trail?

Reference has been made to API Project 43 (Transformation of Organic Material into Petroleum) several times in our progress report. Its importance, in connection with the problem of reservoir fluids, is, we believe, apparent to all. The project is divided into three parts as follows.

43-A The Role of Naturally Occurring Biochemical Agents in Petroleum Genesis.
Scripps Institution of Oceanography—La Jolla, California
Director—Claude E. ZoBell

43-B Studies in the Fields of Chemistry, Bacteriology, Physical Chemistry, and Physics.
Pennsylvania State College—State College, Pennsylvania
Director—Frank C. Whitmore

43-C Studies of the Effect of Radioactivity of the Transformation of Marine Organic Materials into Petroleum Hydrocarbons.
Massachusetts Institute of Technology—Cambridge, Massachusetts
Director—W. T. Mead

The progress of the work of all three divisions, and the information obtained therefrom has been comprehensively reported on both through the API publications and in the

various articles by the directors of the project and their co-workers. No attempt is herein made to thoroughly analyze the findings of all three divisions. This may, in part at least, be necessary at a later date. Research projects like No. 43, with special objectives in view, often develop byproducts or offshoots. Some of the latter may be very important and warrant critical analysis, in order to determine their possible application to methods of finding petroleum.

ZoBell, who has kindly consented to serve as a consultant on our sub-committee, has given us a good statement captioned "Possible Relations of Bacteria to Reservoir Fluids," and therein calls to our attention certain promising lines of investigation, which are worthy of our serious consideration. Some of these already have been included in the report. We are therefore making all of his contribution a part of this progress report.

Possible Relations of Bacteria to Reservoir Fluids

CLAUDE E. ZOBELL

There are several ways in which bacteria may contribute to the formation, transformation and accumulation of petroleum hydrocarbons. Bacterial activity may also contribute to the modification of brine and petroliferous sediments. There is ample evidence that recent marine sediments contain an abundant and biochemically versatile bacterial flora to the greatest depths which have been sampled. Large numbers of living bacteria have likewise been found in samples or reservoir fluids, although it is not known whether these bacteria are indigenous species or if they are adventitious species introduced in the geological formation during or after the drilling of the oil well. Be this as it may, the bacteria found in reservoir fluids like those in recent marine sediments could be functional at the temperature (up to 190°F.), salinity, and hydrostatic pressure of environment where oil is generally found. Moreover, it has been demonstrated that the bacteria in question are endowed with the ability to catalyze the following reactions under conditions which are within the "geological fence."

1. Reduce the nitrogen, oxygen, sulphur and phosphorus content of organic matter, thereby converting the latter into substances which are more petroleum-like.
2. Produce methane and possible other HC's.
3. Produce hydrogen and possibly effect the hydrogenation of unsaturated compounds.
4. Liberate adsorbed oil from certain kinds of sediments and promote the flow of oil by the production of CO_2.
5. Reduce sulphates to H_2S and possibly to sulphur.
6. Effect the diagenesis of sediments in several ways.
7. Influence the pH of brines.
8. Create reducing conditions or low redox potentials.
9. Attack and modify petroleum HC's.

Our knowledge of the foregoing phenomena is very fragmentary. Additional information on the conditions and extent of these reactions in sedimentary material may contribute to our knowledge of the origin of oil. Although all nine of the above reactions are of importance, so big is the problem of the role of bacteria in the formation and transformation of petroleum that only a few specialized aspects of some of the nine reactions are currently receiving the attention of microbiologists on API Research Project 43. In view of the possible importance of the problem, it seems desirable to make provisions for expediting, intensifying and expanding research work on bacteria as geomicrobiological agents with special reference to petroleum. It is believed that such studies may yield information on the origin of oil that may aid the geologist in his quest for subterranean deposits and, moreover, the information may find numerous other practical applications in the petroleum industry.

API Research Project 43A is concentrating primarily upon the closely related reactions 1, 2 and 3 listed above. Very little fundamental research work is being done either at the Scripps Institution of Oceanography or elsewhere on reactions 4–9.

It is my considered opinion that provisions should be made at the earliest opportunity for investigating the "Occurrence and Activity of Bacteria in Reservoir Fluids." Until we know the greatest depth and environmental conditions at which indigenous bacteria may be alive and active, we will not be in a position to appraise the role of bacteria in the formation and transformation of hydrocarbons. Besides determining the lower limits of the biosphere, the meticulous examination of sediment samples rigorously collected from depths greater than any yet critically collected and analyzed may unearth interesting bacterial species unlike any now known. Such bacteria would be of academic interest, but of greater importance (to the objectives of this committee), such bacteria may catalyze reactions which may help to account for the origin of oil. I believe most authorities on the subject will agree that it has been definitely established that bacteria play an important role in conditioning organic matter and the environment of recent sediments. However, little or no oil is found in recent

sediments at the depths which have been critically examined bacteriologically. Therefore, it seems almost axiomatic that preliminary to attributing functions to bacteria further than those observed in these recent sediments, we should first establish beyond question of a doubt the occurrence of active bacteria in petroliferous sediments. It is a difficult problem which will require cooperation, perseverance, and ingenuity, but it is susceptible to scientific methods of attack.

I believe that one of the most important functions of bacteria in the origin and accumulation of oil is to promote the release and flow of oil. Detailed knowledge on the "Effect of Bacteria on the Description and Migration of Oil" may explain many things and also may find practical applications. What we have observed in the laboratory should excite any one who is interested in the origin of oil or in its recovery. However, I am aware of no fundamental research work being done on this problem, and tests for practical application are not in progress. The Penn Grade project makes provisions for a few preliminary tests under specialized conditions, but even this is at a standstill.

Studies on "Bacteria as Indicators of Subterranean Deposits of Oil" or "Geomicrobiological Prospecting" is a practical problem which merits extensive attention. Not only may the fossil remains of bacteria which oxidize volatile hydrocarbons (exclusive of methane) prove to be significant indicators; active HC oxidizers give anomalous results in other methods of "soil analysis" unless their activity is taken into consideration. While there is much fundamental research work to be done on this problem, the practical aspects are so obvious that it is questionable whether the problem should be worked on competitively by the industry or cooperatively as a fundamental research project. Definitely the problem merits immediate and expert attention.

As part of the work of Project 43A we are doing something on the "Bacterial Modification of Petroleum Hydrocarbons" and I plan continued observations on this important problem, but there are many leads which are not being explored owing to the magnitude of the problem and the urgency of other investigations. For example, there are indications that the density of certain crudes has been decreased by bacteria. It has been postulated that sulfate reducers tend to convert paraffinic crudes into naphthenic ones. Eventually we will want complete information on these and other bacteriological problems.

Additional information may be obtained from the Progress Reports of API Research Project 43A, publications numbered 24 through 27 in the following bibliography.

BIBLIOGRAPHY

1. WASHBURNE, C. W., and LAHEE, F. H., "Oil Field Waters," *Problems of Petroleum Geology,* Amer. Assoc. Petrol. Geol. (1934), p. 833.
2. BERGER, W. R., and FASH, R. H., "Relation of Water Analyses to Structure and Porosity in the West Texas Permian Basin," *ibid.*, p. 869.
3. PALMER, CHASE, "The Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479* (1911).
4. BOTSET, HOLBROOK G., "The Radium Content of Some Connate Waters," *Physics,* Vol. 5 (September, 1934), pp. 276–80.
5. GRIM, R. E., "Modern Concepts of Clay Materials," *Jour. Geol.* (April–May, 1942), pp. 225–76.
6. ———, and ROWLAND, R. A., "Differential Thermal Analysis of Clays and Shales, A Control and Prospecting Method," *Illinois State Geol. Survey Cir. 96* (March 1, 1944).
7. HENDRICKS, S. B., "Lattice Structure of Clay Minerals and Some Properties of Clays," *Jour. Geol.* (April–May, 1942), pp. 276–91.
8. NUTTING, P. G., "Adsorbent Clays," *U. S. Geol. Survey Bull. 928-C,* pp. 127–219.
9. KERR, PAUL F., "A Decade of Research on the Nature of Clay," *Jour. Amer. Ceramic Soc.*, Vol. 21 (1938), pp. 267–86.
   (See this article for numerous references on clays.)
10. ROSS, C. A., and KERR, P. F., "Clay Minerals and Their Identity," *Jour. Sed. Petrology,* Vol. 1 (1931), pp. 55–65.
11. VAN TUYL, F. M., and PARKER, B. H., "The Time of Origin and Accumulation of Petroleum," *Colorado School Mines Quar.*, Vol. 36, No. 2, p. 31.
12. WILSON, W. B., "Proposed Classification of Oil and Gas Reservoirs," *Problems of Petroleum Geology,* Amer. Assoc. Petrol. Geol. (1934), pp. 433–46.
13. BARTON, D. C., "Evolution of Gulf Coast Crude Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 7 (July, 1937), pp. 914–46.
14. SAGE, B. H., and LACEY, W. N., "Energy Relations in a Flowing Well," Amer. Petrol. Inst. 16th Annual Meeting, November 14, 1935.
15. STREIFF and ROSSINI, F. D., "Method for Determining Individual Hydrocarbons in Mixtures of Hydrocarbons by Measurement of Freezing Points," *U. S. Bur. Standards Jour. Research* (May, 1944) p. 185.

16. BARTON, D. C., "Natural History of Gulf Coast Crude Oil," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 109–55.
17. ———, "Variation and Migration of Crude Oil at Spindletop, Jefferson County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 618–43.
18. SANDERS, J. MCCONNELL, "Microscopic Examination of Crude Petroleum," *Bull. Inst. Petrol. Tech.*, Vol. 23, No. 167, pp. 525–73.
19. BARTON, D. C., "Correlation of Crude Oil to Gulf Coast," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (April, 1941), pp. 561–92.
20. GRUSE and STEVENS, *Chemical Technology of Petroleum* (1942). (Published formerly as *Petroleum and Its Products.*)
21. THOM, W. T., JR., "Present Status of the Carbon Ratio Theory," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 69–95.
22. ILLINGS, V. C., "The Migration of Oil," *Science of Petroleum*, Vol. 1, p. 209.
23. MCDERMOTT, EUGENE, "Geochemical Exploration (Soil Analysis)," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 24, No. 5 (May, 1940), pp. 860–81.
24. ZOBELL, C. E., "The Role of Bacteria in the Formation and Transformation of Petroleum Hydrocarbons," *Science*, Vol. 102 (October 12, 1945), pp. 364–69.
25. ———, "Bacteria as Geological Agents with Particular Reference to Petroleum," *Petrol. World*, Vol. 40 (June, 1943), pp. 30–43.
26. ———, "Marine Microorganisms Which Oxidize Petroleum Hydrocarbons," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 9 (September, 1943), pp. 1175–93.
27. ———, "Functions of Bacteria in the Formation and Accumulation of Petroleum," *Oil Weekly* (February 18, 1946), pp. 30–36.

MICROCARD LIBRARIES[1]

MARCUS A. HANNA[2]
Houston, Texas

Rock tablets, papyrus, and printed books form one consistent trend toward greater availability of the ideas of men.

It is a startling thought that the first stage of another great forward stride in this sequence has already been taken, in the form of microfilm reproduction, and that this totally new means of transmitting ideas may be made available within a few years at the cost of 5 cents a book in the form of microcards: a whole book of 250 pages, or more, reproduced in microscopic type on the back of a 3×5-inch library card; the entire *Bulletin* of the Geological Society of France in one pocket and the A.A.P.G. *Bulletin* in the other.

Such possibilities would seem to call for extensive revision of our ideas about library facilities. One would not need to be a bibliophile to have an adequate working library in general geology, or in a well documented specialty. Any local geological society could build up the equivalent of the geological section of the Library of Congress in a few years at low cost.

Fremont Rider's book, *The Scholar and the Future of the Research Library*, was reviewed in the September, 1946, number of the *Bulletin*. The research committee believes the time is ripe for the expression of an opinion as to needs in the micro-text field by our membership.

Technique is sufficiently developed to make feasible 250 pages of text, *et cetera* on a 3×5-inch card. Some additional card space will be required for punch system of sorting into subjects. Even with this, however, the cards will be relatively small. The research committee needs to know something of the number of microcards, or rather the number of microcard libraries, which might be desired by the membership of the Association. With this information at hand, the committee would be better prepared to investigate the field of microcard preparation, as well as the field of magnifiers for reading the micro-text.

The committee expects to have postal-card questionnaires forwarded to the member-

[1] Manuscript received, January 22, 1947.

[2] Research committee.

ship at an early date asking for information as to the number of microcards which might be desired. The cost per card and the price of magnifiers that might be produced at an early date can then be determined. Cost estimates will be referred to the membership as soon as available. The information wanted now is the membership's need in terms of *libraries*.

Assuming that an adequate working library for an individual would consist of about 2,000 (microcard) volumes and that a reference library would be 20,000 volumes, and assuming further that unit libraries would be available in different divisions of geology such as invertebrate paleontology, mineralogy, *et cetera*, and that the cost would be $100 for 2,000 cards or $1,000 for 20,000 cards, and that additional individual cards could be purchased at 10 cents each, the research committee needs to know how many of the local societies might purchase reference libraries and how many individuals might purchase working libraries, in how many subjects, over a period of, say, 10 years. With this information we might arrive at a reasonable estimate of the demand for libraries and individual cards from the membership of the A.A.P.G.

Estimates based on past library habits, which in turn have been developed as a result of relative unavailability of adequate library facilities, need sharp revision. Otherwise the estimate of future requirements, on an entirely different cost-availability basis, will lag far behind the actual demand.

This note is published to urge the members to think about and be ready to list their estimates of library requirements when the questionnaire postcard is received. This will not be an order for microcards or microcard libraries. It will be a tabulation of desired facilities, so that the feasibility of securing such facilities at a low cost can be investigated. The plan of micro-text printing is still in its experimental stages, but we believe that the production of geological microcard libraries will be speeded up greatly if there is some reasonable estimate of the future demand. As was Rider's plea, "to begin to issue something at once," we should start now in securing much needed publications in the form of microcards.

ORDOVICIAN SYMPOSIUM

The Pittsburgh Geological Society announces a "Symposium on the Trenton and Sub-Trenton of the Appalachian Area" to be held on Friday, May 16, 1947, in the William Penn Hotel. Papers will be presented and discussed at morning and afternoon sessons, and a banquet will be held in the evening.

The purpose of the symposium is to bring together all information possible on the Trenton and sub-Trenton rocks of the Appalachian basin from the surface section on the eastern and northwestern outcrop belt to the subsurface section across the basin as interpreted by well records and sample studies.

Noted authorities on the Ordovician will be the speakers, and they are now preparing their material. The stratigraphy, structure, and economic aspects of this part of the geological column will be correlated for the entire Appalachian basin.

John T. Galey is chairman of the symposium committee.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 395-400

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

OIL AND GAS FIELD DEVELOPMENT IN UNITED STATES 1945, BY NATIONAL OIL SCOUTS AND LANDMEN'S ASSOCIATION

REVIEW BY CLYDE G. STRACHAN[1]
Tulsa, Oklahoma

Oil and Gas Field Development in the United States, Year Book 1946 (*Review of 1945*). Edited by W. G. Sinclair and E. J. Raisch. 964 pp., maps, tables, charts (7.5×10.5 inches). Published by National Oil Scouts and Landmen's Association, Austin, Texas. Price, $7.50, cloth-bound.

When groups of men assemble a massive collection of data such as that which appears in this book it is a form of impertinence for any single man to presume to undertake a review of it in the ordinary sense of the word. Indeed, the book itself is so thoroughly a review that any extended discussion of it can be little more than a repetition of some of the information that is given in it.

It appears to this reviewer that an oil-company executive or geologist transferred to a new district in the United States should have this book tucked under his arm to read on the train and to have for ready reference on his desk. It carries regional geologic maps, pool maps, stratigraphic sections, production by fields past and present, discoveries and associated data for the year, the location and amount of leasing and geophysical and geological work and even, with the breezy self-confidence of scouts and landmen, pages showing guide fossils of certain areas. Not the least that can be said about it is that it is replete with the information that goes into the small talk that takes place among oil men in hotel rooms and lobbies and cocktail lounges, and with which oil men in conference impress each other with their erudition in oil matters.

Details in the book depend on just what one wants to look up at the moment. Many years ago in a review by this reviewer of a book on the geology of Alabama it was pointed out that no possibility for oil accumulations seemed to be apparent; that was checked in the Year Book, where it is set forth that major companies are doing geophysical work and holding considerable amounts of acreage. Florida is a state we Mid-Continenters wonder about; the Year Book gives it as much space as Arkansas, although no wildcat discoveries in 1945. Crude production in the United States reached a total of 1,710,275,000 barrels, a new high for the third consecutive year; Texas, as usual the leader, made 44 per cent of this production.

And so on, just about what you want to know concerning the general operations of oil companies in the United States.

RECENT PUBLICATIONS

AFRICA

**Bulletin du Service Géologique* (Bulletin of the Geological Office), No. 1 (Leopoldville, Belgian Congo, 1945). 184 pp., illus. (maps, pls., figs., tables, photographs). Le Service Géologique du Congo Belge et du Ruanda-Urundi. In French. The following papers are included.

[1] Gulf Oil Corporation.

"La stratigraphie du système du Kalahari et du système du Karroo au Congo Occidental" (Stratigraphy of Kalahari and Karroo Systems in Western Congo), by J. Lepersonne.

"La géologie de l'Ituri. -Le groupe de la Lindi" (Geology of Ituri. Lindi Group), by M. Sluys.

BRAZIL

*_Relatorio de 1944_ (Report of the National Petroleum Council, Brazil, for 1944). 280 pp., 55 figs., 67 photographs. Supplement contains 39 pp., 9 figs. Results of geological and geophysical work in the state of Bahia (pp. 61–101) and in the Paraná Basin (pp. 225–41); general program of geological and geophysical investigations for 1945 (pp. 271–76). Conselho Nacional do Petróleo, Rio de Janeiro, Brazil (1946). In Portuguese.

CALIFORNIA

*"The Geology and Development of the West Newport Field," by W. E. Dunlap and A. L. Hunter. _Petrol. World_, Vol. 43, No. 12 (Los Angeles, December, 1946), pp. 46–50; structural map, and cross section through field. The most southerly of a chain of fields along the NW.-SE. trending Inglewood-Newport fault system.

*"Some Permeability Experiments on Cores from the Stevens Sand, Paloma Field, California," by K. T. Miller, F. Morgan, M. Muskat. _Producers Monthly_, Vol. 11, No. 1 (Bradford, Pennsylvania, November, 1946), pp. 31–34; 4 figs. Further light on problem of permeability determinations of clay-containing oil sands.

FRANCE

*"Étude de la microfaune du chantier de Gensac (Haute-Garonne)" (Study of the Microfauna in the Gensac Field, in Haute-Garonne), by J. Sigal. _Revue de l'Institut Français du Pétrole et Annales des Combustibles Liquides_, Vol. 1, No. 1 (Paris, October, 1946), pp. 16–32; 10 pls. Author shows that in this field a study of the composition and preservation characteristics of the microfauna, in relation to the nature of the sedimentation, makes possible well-to-well correlations.

GENERAL

*"How Old Is the Colorado River?" by Chester R. Longwell. _Amer. Jour. Sci._, Vol. 244, No. 12 (New Haven, Connecticut, December, 1946), pp. 817–35; 6 pls., 3 figs. Writer concludes that " . . . it is not now possible to outline a full history of the Colorado River drainage without resort to speculation—presumably the river acquired its present course west of the Plateau after late Miocene time."

*"Observations on Gastropod Protoconchs. Part III—Some Protoconchs in Busycon, Fusinus, Heilprinia, Hesperisternia, and Urosalpinx," by Burnett Smith. _Palaeontographica Americana_, Vol. 3, No. 21 (Palaeontological Research Institution, Ithaca, New York, November 27, 1946). 19 pp., 1 pl.

Geological Map of North America, compiled by George W. Stose, U. S. Geol. Survey. Two sheets, 76×55 inches when mounted together. Scale, 1:5,000,000. Printed in 19 colors, a total of 90 map units being represented by color patterns. Detailed statement of formations included under each map unit given in Explanation of the Legend. A completely new compilation and not a revision of the Geological Map of North America published in 1911. Compilation financed by grants made by the Geological Society of America, the American Philosophical Society, and the American Association of Petroleum Geologists. Mail orders, accompanied by remittance ($3.50 per copy), should be sent to the Geological Society of America, 419 West 117th Street, New York 27, N. Y.

*"Abstracts and Index (July–December)." _Bull. Geol. Soc. America_, Vol. 57, No. 12, Pt. 2 (New York, December, 1946), pp. 1173–1288. Abstracts of papers on the program

of (1) the Mineralogical Society of America, the Paleontological Society, the Society of Vertebrate Paleontologists, and the Geological Society of America, meeting in Chicago, Illinois, December 26–28, 1946; (2) the Cordilleran Section of the Geological Society of America and the Pacific Coast Branch of the Paleontological Society, meeting in Berkeley, California, April 19–20, 1946; (3) Section E, American Association for the Advancement of Science, meeting in St. Louis, Missouri, March 27–29, 1946, and in Cambridge, Massachusetts, December 30–31, 1946.

*"Pressure Maintenance by Conjoint Injection of Gas and Water—A Wartime Suggestion," by Frederick Squires. *Illinois Geol. Survey Cir. 103* (Urbana, 1944). 14 pp., 13 figs. Reprinted from *Oil and Gas Jour.*, Vol. 42, No. 42 (Tulsa, February 24, 1944).

*"Les procédés Schlumberger d'exploration electrique des sondages" (The Schlumberger Procedure of Electrical Logging), by M. Martin. *Bulletin de l'Association Française des Techniciens du Pétrole*, No. 59 (Paris, October 1, 1946), pp. 55–86; 23 figs. Theory and application of electrical well logging.

"Isogonic Chart for 1945, United States." Revised edition of *U. S. Coast and Geodetic Survey Chart 3077*, issued July, 1946. 31×47 inches. Scale, 1:5,000,000. Printed in 5 colors, on heavy chart paper. Lines of equal declination and of equal annual change have been completely redrawn. Mail orders should be sent Director, U. S. Coast and Geodetic Survey, Washington 25, D. C. Price, $0.40.

*"Possibilities and Problems of Drilling beyond the Continental Shelves," by Henry Emmett Gross. *Petrol. Tech.*, Vol. 9, No. 6 (New York, November, 1946). 7 pp., 4 figs. *Amer. Inst. Min. Met. Eng. Tech. Pub. 2095.*

*"Evaluation of Pressure Maintenance by Internal Gas Injection in Volumetrically Controlled Reservoirs," by E. Charles Patton, Jr. *Ibid.*, *Tech. Pub. 2098.* 41 pp., 9 figs., 3 tables. Comprehensive discussion of proposed method for utilizing determinable basic physical facts about tight, volumetric-type reservoirs and their contained fluids, to determine feasibility of injecting gas therein and to estimate minimum profits.

*"Geothermal Gradients in Mid-Continent and Gulf Coast Oil Fields," by Earl A. Nichols. *Ibid.*, *Tech. Pub. 2114.* 4 pp., 1 table, 2 figs., including contour map showing geographical variation in geothermal gradients in Mid-Continent and Gulf Coast Oil fields.

*"Clay Research and Oil Development Problems," by J. G. Griffiths. *Jour. Inst. Petroleum*, Vol. 32, No. 265 (London, January, 1946), pp. 18–31, 1 table. Significance of the clay minerals in the problem of oil exploitation and production.

Personality and English in Technical Personnel, by Philip B. McDonald. 424 pp. Development of personality and improvement in the usage of language by the engineer. D. Van Nostrand Company, New York (1946). Price, $3.75.

*"Structural Correlation of Micromagnetic and Reflection Data," by W. P. Jenny. *Oil Weekly*, Vol. 124, No. 3 (Houston, December 16, 1946), pp. 32–33; 4 figs.

*"Paleontology and Its Relation to Petroleum Geology," by J. Harlan Johnson. *Ibid.*, pp. 36–37; illus.

Petroleum Production. Vol. II: Optimum Rate of Production, by Park H. Jones. 295 pp., illus. Reinhold Publishing Corporation, New York (1947). Price, $4.50.

*"Alignment Chart for Solving Problems Involving the Relative Position of Geologic Markers," by L. R. Merryman. *California Oil World*, Vol. 39, No. 22 (Los Angeles, Second Issue, November, 1946), pp. 50–51; 3 figs. Chart reproduced and its application illustrated.

**Oil for Victory*, by the editors of *Look*. 287 pp., profusely illustrated with photographs. Graphic story of supplying oil for World War II. 6.5×9.625 inches, cloth. Whittlesey House, McGraw-Hill Book Company, Inc., New York (1946). Price, $3.50.

The Mines Magazine, 11th annual petroleum number (1946). Colorado School of Mines Alumni Assoc., 734 Cooper Building, Denver, November, 1946. 116 pp., 54 illus., 15 drawings, 11 maps, 10 tables. Price, $1.00. Special articles include the following.

"Oil Exploration in the Middle East," by E. DeGolyer.

"Conquest of Ecuador's Oil in Pizarro's Footsteps," by W. E. Wallis.

"The Low Velocity Layer in Seismic Exploration," by Paul L. Lyons.

"Rangely Oil Field, Rangely, Colorado," by Bernard M. Bench.

"Continental Shelves," by H. V. W. Donohoo.

"Water Flooding Oil Formation in Kansas," by George E. Abernathy and John Mark Jewett.

"Oil Development in Saudi Arabia," by Dale Nix.

"Limit of Accuracy of Seismic Work in Alberta," by L. W. Storm.

"1946 Developments in the Louisiana Gulf Coast," by Wm. G. Blackwell.

*"Core Analysis—Practical Application to Oil and Gas Reservoirs," by J. H. Campbell. *Petrol. Engineer*, Vol. 18, No. 3 (Dallas, December, 1946), pp. 100–04; 5 figs.

ILLINOIS

"Developments in Eastern Interior Basin in 1945," by A. H. Bell. *Illinois Geol. Survey Bull. 53* (Urbana, 1946). Reprinted from *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 6 (June, 1946), pp. 879–85; 1 fig.

"Oil and Gas Development in Illinois in 1945," by A. H. Bell and V. Kline. *Ibid.*, *Bull. 54* (Urbana, 1946).

KANSAS

*"Lime-Secreting Algae from the Pennsylvanian and Permian of Kansas," by J. Harlan Johnson. *Bull. Geol. Soc. America*, Vol. 57, No. 12, Pt. 1 (New York, December, 1946), pp. 1087–1120; 10 pls., 5 figs., 4 tables. Description of algae from 74 formations or named formation members which range in age from the top of the Lower Pennsylvanian up almost to the Lower Permian. Locally, algae as rock builders are considered important. Relation of algal deposits to the cyclothems of deposition is discussed.

MONTANA

"Structure Contour Map of Cut Bank-West Kevin Border Districts, Glacier, Toole, and Pondera Counties, Montana," by C. E. Erdmann, William Beer, and J. W. Nordquist. *U. S. Geol. Survey* (December, 1946). Covers Ts. 30 to 37 N., Rs. 3 to 8 W., 1,728 square miles. Thorough revision of preliminary structure-contour map of the Cut Bank region by C. E. Erdmann and N. A. Davis, released in May, 1939. 100-foot contours drawn on top of Colorado shale. Areal geology, stratigraphic cross section, culture, field development, and production figures for Cut Bank field are included. Mail orders should be sent Director, Geological Survey, Washington 25, D. C. Price, $0.25.

"New Maps of Kevin-Sunburst Oil Field," by C. E. Erdmann, A. B. Cozzens, J. T. Gist, and J. W. Nordquist. *U. S. Geol. Survey* (December, 1946). 2 sheets (A and B), covering 64 square miles in and adjacent to T. 35 N., R. 4 W., Toole County, Montana. Scale, 1 inch equals 1 mile. The first of a new series that will eventually cover the entire Kevin-Sunburst oil field. Structural details based on plane-table mapping. Sheet A shows culture, well status, surface geology, geologic structure (shown by 20-foot contours drawn on the top of the Colorado shale), and a composite section of 940 feet of exposed rocks. Sheet B shows 20-foot contours on the eroded surface of the Madison limestone, wells that reach the Madison, a standard well log, and a note on production in the High Gravity pool. Mail orders should be sent Director, Geological Survey, Washington 25, D. C. Price, $0.10 each.

NETHERLANDS

*"De Tectoniek van het Carboon in het Zuid-Limburgsche Mijngebied" (The Tectonics of the Carboniferous in the South Limburg Coal Mine District), by H. G. J. Sax.

Mededeelingen van de Geologische Stichting, Ser. C, I, 1, No. 3. Ernest van Aelst, Uitgever, Maastricht, Netherlands (1946). 77 pp., 7 pls., 18 figs., 2 tables. 9×11.75 inches. Paper cover. Foreword and text in Dutch. Abridged translation in English. One of a series of publications in geological-paleontological research in the subsurface of the Netherlands, under the direction of W. A. J. M. van Waterschoot van der Gracht, and L. U. de Sitter, W. J. Longmans, P. Tesch, and collaborators.

*"Eine Monographische Bearbeitung der Karbonischen Megasporen (A Monograph on Carboniferous Megaspores)," by S. J. Dijkstra, in collaboration with P. H. van Vierssen Trip. *Ibid.*, Ser. C, III, 1, No. 1 (1946). 101 pp., 7 charts, 16 pls. (184 figs.), 1 text fig., 8 tables. In German.

*"The Pliocene and Lower Pleistocene Gastropods in the Collections of the Geological Foundation in the Netherlands," by C. Beets. *Ibid.*, Ser. C, IV, 1, No. 6 (1946). 166 pp., 1 index map, 6 pls. (48 figs.), 1 text fig. Foreword in Dutch. Text in English.

NEW MEXICO

*"Geology of the Los Pinos Mountains, New Mexico," by J. T. Stark and E. C. Dapples. *Bull. Geol. Soc. America*, Vol. 57, No. 12, Pt. 1 (New York, December, 1946), pp. 1121–72; 1 fig., 6 pls. Pennsylvanian and Permian strata unconformably overlie the pre-Cambrian rocks comprising the core of the Los Pinos Mountains along the Rio Grande Valley in central New Mexico. The pre-Cambrian rocks have been thrust eastward, overturning the Paleozoic sediments.

OHIO, KENTUCKY, WEST VIRGINIA

"Map of Berea Sand of Southern Ohio, Eastern Kentucky, and Southwestern West Virginia," by James F. Pepper, David F. Demarest, Charles W. Merrels, 2d., and Wallace deWitt, Jr., *U. S. Geol. Survey Prelim. Map 69*, Oil and Gas Investig. Ser. (December, 1946). 44×46 inches. Scale, 1 inch equals 3 miles. Oil and gas pools in the Berea are shown in green and red, respectively. Oil and gas possibilities of the Berea sand are illustrated and discussed. Variations in thickness of the sand are shown by shading and by lines indicating equal thickness. Included, smaller maps show regional geologic structure, the location and extent of areas of Berea sand of similar depositional history, and a geologic cross section showing the regional stratigraphic relations of the Berea and adjacent formations. Mail orders should be sent Director, Geological Survey, Washington 25, D. C. Price, $0.60.

OKLAHOMA

*"Secondary Recovery in the Nowata-Claggett Area," by Anthony Gibbon. *Oil Weekly*, Vol. 124, No. 2 (Houston, December 9, 1946), pp. 48–57; 4 figs., 2 tables.

ROCKY MOUNTAINS

1945 Rocky Mountain Petroleum Yearbook. 390 pp. Published by Petroleum Publishers, Inc., 730 17th Street, Denver 2, Colorado.

SOUTH AMERICA

*"Oil Resources of South America," anonymous. *World Petroleum*, Vol. 17, No. 13 (New York, December, 1946), pp. 54–57; 1 map (showing Tertiary basins and oil fields), 5 photographs. Oil resources, geology, and exploration activities summarized.

*"Argentine Petroleum Industry," by Alberto Landoni, and Alberto Zanetta. 2d instalment of a condensed translation prepared by Rolt Hammond, from the authors' original contribution, "Historia del desarrollo de la industria petrolera en el pais," first published in *La Ingenieria*, 49 (1945), pp. 646–62. *Petroleum*, Vol. 9, No. 12 (London,

December, 1946), pp. 288–90; 3 outline maps, showing areas in Argentina covered by topographic, geological, and geophysical surveys. Exploration activities, drilling, and development are reviewed.

TEXAS

*"Geological Group Develops Columnar Section of Pre-Permian Formations along Central Basin Platform," by Jackson M. Barton. *Oil and Gas Jour.*, Vol. 45, No. 32 (Tulsa, December 14, 1946), pp. 106–7; illus. Results of work of pre-Permian study group of the West Texas Geological Society.

**Structural Map of Texas*, by E. H. Sellards and Leo Hendricks. Third edition, revised (November, 1946). 4 sheets, each approx. 42×54 inches. Scale, 1 inch equals 8 miles. In colors, showing oil and gas fields, faults, salt domes, and sturctural contours with 500-foot interval on key stratigraphic horizons. Each sheet, corresponding with the 4 quadrants of the state, complete with legend. Univ. Texas Bur. Econ. Geol. (Austin, December, 1946). Price, postpaid, $1.50 per sheet, or $5.00 for complete set of 4 sheets.

*"Carthage Gas Field Development," by Fred K. Foster. *Oil Weekly*, Vol. 124, No. 4 (Houston, December 23, 1946), pp. 33–44; 6 pls., 1 table. History, development, stratigraphy, structure, and gas-condensate production of field covering 250,000 acres.

TURKEY

*"Kürzot Petrol Madeni ve Havalisi" (Kurzot Oil), by Kemal Lokman. *Maden Tetkik ve Arama Enstitüsü Mecmuasi*, No. 1/35—1946 Sayisindan (Ankara, 1946), pp. 95–101; 2 figs. Description of the Kurzot oil seepage near the boundary of eastern Turkey and Iran and exploration work of the Mining Research Institute of Turkey during 1937–45. Daily average petroleum output of tunnel system only 7½ kilograms. Exploratory drilling and geological and geophysical surveys reveal structurally complex conditions, with large areas of igneous and metamorphic rocks. The drilling of deep wells in this area is not recommended. Text in Turkish; author's résumé in English.

DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 21, No. 1 (January, 1947).

"Ordovician Fossils from the Southwestern Part of the Canadian Arctic Archipelago," by A. K. Miller and Walter Youngquist.

"A Goniatite from the Mississippian Boone Formation of Missouri," by A. K. Miller.

"Invertebrate Fossils from Deep Wells along the Atlantic Coastal Plain," by Horace G. Richards.

"Fossil Plants and Human Footprints in Nicaragua," by Roland W. Brown.

"*Nubecularia* from the Pennsylvanian and Permian of Kansas," by J. Harlan Johnson.

"*Permopora keenae*, a New Late Permian Alga from Texas," by Maxim K. Elias.

"Analysis and Revision of Eleven Lower Cambrian Trilobite Genera," by Christina Lochman.

"Terminology for Describing Cambrian Trilobites," by B. F. Howell, E. A. Frederickson, C. Lochman, G. O. Raasch, and F. Rasetti.

"*Remopleurides Sinclairi*, New Name," by G. Arthur Cooper and Cecil H. Kindle.

"Paleoecological Import of Certain Relationships of Marine Animals to Salinity," by Gordon Gunter.

"Three Nomenclatural Problems in Liassic Ammonoidea," by Otto Haas.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 401-420, 4 FIGS.

THE ASSOCIATION ROUND TABLE

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

EARL B. NOBLE, *chairman*, Union Oil Company of California, Los Angeles, California
EDWARD A. KOESTER, *secretary*, Darby & Bothwell, Wichita, Kansas
MONROE G. CHENEY, Anzac Oil Corporation, Coleman, Texas
D. PERRY OLCOTT, Humble Oil and Refining Company, Houston, Texas
GAYLE SCOTT, Texas Christian University, Fort Worth, Texas

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL: PHILIP B. KING (1949)

REPRESENTATIVES ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

CARROLL E. DOBBIN — ROBERT J. RIGGS

REPRESENTATIVES ON COMMISSION ON CLASSIFICATION AND NOMENCLATURE OF ROCK UNITS

M. G. CHENEY (1947), *chairman* — JOHN G. BARTRAM (1948) — WAYNE V. JONES (1949)

STANDING COMMITTEES

FINANCE COMMITTEE

FRANK R. CLARK (1947), *chairman* — JOSEPH E. POGUE (1948) — JOHN S. IVY (1949)

TRUSTEES OF REVOLVING PUBLICATION FUND

W. D. KLEINPELL (1947), *chairman* — W. B. WILSON (1948) — WILLIAM B. HEROY (1949)

TRUSTEES OF RESEARCH FUND

E. O. MARKHAM (1947), *chairman* — T. S. HARRISON (1948) — ROBERT W. CLARK (1949)

BUSINESS COMMITTEE

C. L. MOODY (1947), *chairman*, Ohio Oil Company, Shreveport, Louisiana
ROY M. BARNES (1947), *co-chairman*, Continental Oil Company, Los Angeles, California

A. P. ALLISON (1947)
WARREN D. ANDERSON (1948)
E. J. BALTRUSAITIS (1947)
FRANK W. BELL (1948)
OLIN G. BELL (1948)
JOSEPH L. BORDEN (1947)
MAX BORNHAUSER (1947)
IRA H. BRINKERHOFF (1948)
MONROE G. CHENEY (1947)
H. E. CHRISTENSEN (1948)
FRANK R. CLARK (1948)
CARLE H. DANE (1948)
ADOLPH DOVRE (1947)
ROLLIN ECKIS (1947)
STANLEY G. ELDER (1948)
ROBERT M. ENGLISH (1947)
GLENN C. FERGUSON (1947)
GEORGE R. GIBSON (1947)
W. DOW HAMM (1948)
GLENN D. HAWKINS (1947)
L. W. HENRY (1947)
J. S. HUDNALL (1947)
EDWIN H. HUNT (1947)
JOHN W. INKSTER (1947)
ROBERT L. KIDD (1948)
EDWARD A. KOESTER (1947)
ROBERT N. KOLM (1948)
CLAUDE E. LEACH (1948)
PAUL B. LEAVENWORTH (1947)
LYNN K. LEE (1947)
SHIRLEY L. MASON (1948)
GAIL F. MOULTON (1947)
JERRY B. NEWBY (1947)
EARL B. NOBLE (1948)
D. PERRY OLCOTT (1947)
ELISHA A. PASCHAL (1948)
F. W. ROLSHAUSEN (1947)
J. J. RUSSELL, JR. (1948)
GAYLE SCOTT (1947)
ROBERT L. SIELAFF (1947)
IRA H. STEIN (1947)
HENRYK B. STENZEL (1947)
D. E. TAYLOR (1948)
G. D. THOMAS (1948)
HENRY N. TOLER (1947)
C. W. TOMLINSON (1948)
GEORGES VORBE (1947)
W. O. ZIEBOLD (1947)

COMMITTEE FOR PUBLICATION

LYNN K. LEE (1948), *chairman*, Pure Oil Company, Fort Worth, Texas

1947	1948	1949
J. E. BILLINGSLEY	JOSEPH L. BORDEN	JOHN G. GRAY
DON O. CHAPELL	W. S. HOFFMEISTER	GEORGE C. GROW
J. I. DANIELS	J. M. KIRBY	BENJAMIN F. HAKE
HOLLIS D. HEDBERG	E. RUSSELL LLOYD	MASON L. HILL
LEE C. LAMAR	HOMER A. NOBLE	GEORGE S. HUME
E. A. PASCHAL	THOMAS F. STIPP	JAMES A. MOORE
K. K. SPOONER	C. W. WILSON, JR.	ROBERT B. NEWCOMBE
T. E. WEIRICH		E. A. WENDLANDT

RESEARCH COMMITTEE

SHEPARD W. LOWMAN (1947), *chairman*, Shell Oil Company, Houston, Texas

1947	1948	1949
E. R. ATWILL	RONALD K. DEFORD	L. C. CASE
ROLAND F. BEERS	MARCUS A. HANNA	K. C. HEALD
PARKE A. DICKEY	MARSHALL KAY	WILLIAM C. IMBT
G. C. GESTER	PHILIP B. KING	W. C. KRUMBEIN
ROBERT N. KOLM	A. I. LEVORSEN	F. M. VAN TUYL
GRAHAM B. MOODY	W. W. RUBEY	W. A. WALDSCHMIDT
D. PERRY OLCOTT	W. T. THOM, JR.	
ROBERT J. RIGGS	L. G. WEEKS	
JOSEPH A. SHARPE		

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

HENRY J. MORGAN, JR. (1948), *chairman*, Atlantic Oil and Refining Company, Dallas, Texas

1947	1948		1949
STUART K. CLARK	JOHN G. BATRTRAM	A. E. BRAINERD	HORACE G. RICHARDS
ROY T. HAZZARD	ROBERT H. DOTT	ROLLIN ECKIS	GAYLE SCOTT
W. J. HILSEWECK	E. FLOYD MILLER	ROSS L. HEATON	G. D. THOMAS
WAYNE V. JONES	HUGH D. MISER	J. H. C. MARTENS	H. D. THOMAS
W. ARMSTRONG PRICE	RAYMOND C. MOORE	TOM MCGLOTHLIN	ROBERT O. VERNON
		GROVER E. MURRAY	L. E. WORKMAN

SUB-COMMITTEE ON CENOZOIC

GROVER E. MURRAY (1949), *chairman*, Magnolia Petroleum Company, Jackson, Mississippi

ROBERT O. VERNON (Atlantic Coast)
ROLLIN ECKIS (Pacific Coast)
TOM MCGLOTHLIN (Eastern Gulf Coast)

SUB-COMMITTEE ON MESOZOIC

G. D. THOMAS (1949), *chairman*, Shell Oil Company, Inc., Shreveport, Louisiana

R. T. HAZZARD (Gulf Coast)
ROSS L. HEATON (Rocky Mts. and Great Plains)
HORACE G. RICHARDS (Atlantic Coast)

SUB-COMMITTEE ON PALEOZOIC

ROBERT H. DOTT (1948), *chairman*, Oklahoma Geological Survey, Norman, Oklahoma

H. D. THOMAS (Rocky Mts. and Great Plains)
STUART K. CLARK (Mid-Continent)
L. E. WORKMAN (Eastern Interior)
W. J. HILSEWECK (Southwestern U. S. A.)
J. H. C. MARTENS (Appalachian Region)

ADVISORY AND SPECIAL PROJECTS SUB-COMMITTEE

JOHN G. BARTRAM (1948), *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

ARTHUR E. BRAINERD
WAYNE V. JONES
E. FLOYD MILLER
HUGH D. MISER
RAYMOND C. MOORE
W. ARMSTRONG PRICE
GAYLE SCOTT

COMMITTEE ON APPLICATIONS OF GEOLOGY

KENNETH K. LANDES (1947), *chairman*, University of Michigan, Ann Arbor, Michigan

1947	1948	1949
LEO R. FORTIER	ROBERT I. DICKEY	E. M. BAYSINGER
THOMAS A. HENDRICKS	CHARLES R. FETTKE	CHARLES J. DEEGAN
W. T. NIGHTINGALE	OLAF P. JENKINS	L. B. HERRING
PAUL WEAVER	NICHOLAS A. ROSE	R. A. STEHR

MEDAL AWARD COMMITTEE

EARL B. NOBLE, *chairman*, Union Oil Company, Los Angeles, California
F. W. ROLSHAUSEN, *ex officio*, president of S.E.P.M.
J. J. JAKOSKY, *ex officio*, president of S.E.G.

1947	1948	1949
H. B. FUQUA	A. RODGER DENISON	RUSSELL S. MCFARLAND
THORNTON DAVIS	VIRGIL B. COLE	RAYMOND F. BAKER
HUGH D. MISER	J. EDMUND EATON	C. R. MCCOLLOM

COMMITTEE ON STATISTICS OF EXPLORATORY DRILLING

F. H. LAHEE (1947), *chairman*, Sun Oil Company, Box 2880, Dallas, Texas
PAUL WEAVER (1948), *vice-chairman*, Gulf Oil Corporation, Box 2100, Houston, Texas

1947	1948	1949
ALFRED H. BELL	KENNETH COTTINGHAM	ROBERT L. BATES
R. J. CULLEN	RALPH E. ESAREY	STANLEY G. ELDER
W. LLOYD HASELTINE	FENTON H. FINN	COLEMAN D. HUNTER
W. J. HILSEWECK	JOHN W. INKSTER	ROBERT C. LAFFERTY, JR.
W. S. MCCABE	GRAHAM B. MOODY	D. J. MUNROE
JOHN C. MILLER	CHARLES H. ROW	T. F. PETTY
C. L. MOODY		GLENN C. SLEIGHT
		C. W. WILSON

DISTINGUISHED LECTURE COMMITTEE

FRED H. MOORE, *chairman*, Magnolia Petroleum Company, Mt. Vernon, Illinois

1947	1948	1949
LEE H. CORNELL	EVERETT F. STRATTON	HUGH R. BRANKSTONE
JOHN L. FERGUSON	CARROLL M. WAGNER	
W. J. HILSEWECK		

SPECIAL COMMITTEES

NATIONAL SERVICE COMMITTEE

M. GORDON GULLEY, *chairman*, Gulf Oil Corporation, Pittsburgh, Pennsylvania

FRITZ L. AURIN	CHARLES B. HUNT	ED. W. OWEN
OLIN G. BELL	OTTMAR F. KOTICK	W. T. SCHNEIDER
CHARLES E. ERDMANN	LAURENCE E. NUGENT, JR.	

COMMITTEE ON BOY SCOUTS LITERATURE

MAX W. BALL, *chairman*, Denver National Bank Building, Denver, Colorado

A. C. BACE	DON L. CARROLL

EDUCATION COMMITTEE

JAMES GILLULY, *chairman*, University of California, Los Angeles, California

STUART K. CLARK	RONALD K. DEFORD	ROY R. MORSE
MORGAN J. DAVIS	HENRY V. HOWE	THERON WASSON

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

John Mason Clayton, Dallas, Tex.
R. A. Stehr, R. S. McFarland, Barney Fisher
Albert Taylor Eyler, Jr., Tulsa, Okla.
Hilton L. Rickard, Sherman A. Wengerd, Sherwood Buckstaff
Don Gilkison, Cody, Wyo.
R. B. Ross, Clyde G. Strachan, Louis W. Gardner
Robert Beattie Gilmore, Dallas, Tex.
Lewis W. MacNaughton, E. DeGolyer, James H. Gardner
Albert Lloyd Latta, Tulsa, Okla.
Max Littlefield, W. B. Wilson, Jed B. Maebius
C. Brooks Pierce, Tulsa, Okla.
John W. Inkster, J. H. Brown, Garth W. Caylor
Walter D. Abel, Los Angeles, Calif.
Milton W. Lewis, Walker S. Clute, Harry P. Stolz
William Burrus Armstrong, Tulsa, Okla.
H. W. Peabody, V. L. Frost, E. A. Paschal
Donald Bell, Midland, Tex.
Leo R. Newfarmer, W. A. Waldschmidt, A. L. Repecka
Edward William Beltz, Douglaston, N. Y.
Lewis G. Weeks, Raymond Leibensperger, D. Dale Condit
Arthus Charles Bevan, Charlottesville, Va.
W. E. Wrather, Hugh D. Miser, William W. Rubey
Edward Louis Birminghan, Jr., Wichita, Kan.
Rieman S. Webb, Donald M. Allen, B. W. Beebe
Harry Dudley Brookby, Wichita Falls, Tex.
Donald Kelly, Dolphe E. Simic, John A. Kay
Rosella Leota Bunch, Tyler, Tex.
A. C. Wright, Howard H. Lester, G. J. Loetterle
Victor Bychok, Dallas, Tex.
A. E. McKay, Edgar Kraus, O. C. Clifford, Jr.
Robert Mills Chapman, Washington, D. C.
Earl T. Apfel, John R. Ball, Carle H. Dane
Lawrence W. Chasteen, Los Angeles, Calif
Harvey W. Lee, J. R. Pemberton, Milton W. Lewis
Donald Crary, Houston, Tex.
George I. McFerron, George S. Buchanan, Roy F. Bennett
Paul Fuenning, Denver, Colo.
Laurence Brundall, A. R. Wasem, E. C. Reed
Willard Dale Goodrich, Wichita, Kan.
A. L. Beekly, E. G. Woodruff, E. F. Miller
Ralph Clare Graham, Houston, Tex.
William F. Calohan, Dan J. White, Jr., Earle N. Armstrong

Frederick Jamieson Hamilton, Calgary, Alta., Canada
W. P. Hancock, D. B. Layer, F. A. McKinnon
Sigmund Immanuel Hammer, Pittsburgh, Pa.
E. A. Eckhardt, K. C. Heald, M. G. Gulley
Thomas Jesse Johnson, Abilene, Tex.
V. C. Perini, Jr., E. M. Funkhouser, John P. Byram
Frederick Alexander Kidd, Calgary, Alta., Canada
Conrad O. Hage, J. C. Scott, J. R. McGehee
Enrique Tomas Mauri, La Plata, Argentina, S. A.
Oswaldo Bracaccini, Rodolfo Martin, Juan J. Zunino
Carl Landram Maxey, Oklahoma City, Okla.
H. E. Rankin, J. L. Lindner, Dean C. Wellman
James Roy Maxey, Caracas, Venezuela, S. A.
George E. Wagoner, R. W. Edmund, Rolf Engleman
Patrick Bernard McGrath, Altadena, Calif.
Stephen G. Gester, Robert P. Miller, W. A. Findlay
Sherman K. Neuschel, Washington, D. C.
J. Fred Smith, Jr., Thomas A. Hendricks, Paul Averitt
Levi F. Noble, Valyermo, Calif.
James Gilluly, Cordell Durrell, M. N. Bramlette
Don W. Payne, Wichita, Kan.
L. W. Kesler, Alvin E. Cheyney, Frank R. Kittredge
Hans Renz, Lima, Peru, S. A.
H. I. Tschopp, D. Trumpy, E. Kundig
Daniel Schneegans, Paris, France
Edward D. Lynton, H. de Cizancourt, Marcel Schlumberger
Sherril Arthur Shannon, Wichita, Kan.
Harold O. Smedley, Jack H. Heathman, Roy P. Lehman
Frederick A. Smith, Houston, Tex.
Roy F. Bennett, George I. McFerron, George S. Buchanan
Jesse Emory Spencer, Casper, Wyo.
D. B. Winfrey, J. H. McCoy, R. H. Tucker
John A. Trimmell, Great Bend, Kan.
N. D. Clark, K. T. Woodman, T. G. Wright

FOR ASSOCIATE MEMBERSHIP

Lynn D. Allen, Caracas, Venezuela, S. A.
Roy W. Pearce, Adrian E. Mix, Frank L. LeRoy
Dewey Follett Bartlett, Tulsa, Okla.
Maurice R. Teis, Robert E. Garrett, John W. Merritt
Edwin Conger Buffington, Pasadena, Calif.
Ian Campbell, John P. Buwalda, T. F. Harriss
James Wood Clarke, Emory University, Ga.
Arthur C. Munyan, D. J. Jones, A. C. McFarlan
William Jones Cox, Jr., Emory University, Ga.
Arthur C. Munyan, D. J. Jones, A. C. McFarlan
Paul Louis Hayes, Los Angeles, Calif.
Wilbur D'Arcy Rankin, Stanley C. Herold, Donuil Hillis
Frank Herman Holcomb, Dallas, Tex.
L. C. Snider, F. L. Whitney, Fred M. Bullard

Harold George Johnson, Ben Wheeler, Tex.
Frederick A. Burt, Harold Vance, S. A. Lynch
William Ernest McBroom, Wichita Falls, Tex.
John A. Kay, Ellen Posey Bitgood, J. B. Moorhead
Marvin Phillip Meyer, Urbana, Ill.
M. M. Leighton, H. R. Wanless, A. H. Bell
Jose Henrique Pantin, Caracas, Venezuela, S. A
F. A. Sutton, Siemon W. Muller, A. I. Levorsen
Bill R. Payne, Spring Hill, Ala.
W. C. Blackburn, W. F. Bowman, Hal P. Bybee
William Arthur Petersen, Denver, Colo.
Warren O. Thompson, Elmer L. Lucas, A. E. Brainerd
Randall Wayne Russell, McCamey, Tex.
Frederick A. Burt, Harold Vance, S. A. Lynch
Basil Victor Savoy, Media, Pa.
F. M. Van Tuyl, J. Harlan Johnson, Ben H. Parker
Emmett E. Schieck, Casper, Wyo.
R. H. Beckwith, H. D. Thomas, Max L. Krueger
Kia-Kang Wang, Baton Rouge, La.
Richard Joel Russell, H. V. Howe, Chalmer J. Roy
Charles Gardner Allen, Taft, Calif.
J. D. Bainton, W. F. Barbat, E. H. Burtner
John Victor Bryan, Chickasha, Okla.
Charles E. Decker, Frank H. Worrell, C. G. Lalicker
Sailendra Kumer Chakravorty, Golden, Colo.
C. G. Lalicker, W. S. Levings, F. M. Van Tuyl
James Marvin Cunningham, Baton Rouge, La.
Richard Joel Russell, H. N. Fisk, Chalmer J. Roy
Jack Myler DeLong, Tyler, Tex.
Laurence S. Melzer, Edmund M. Spieker, George W. White
Robert Flanders Dewey, Wichita, Kan.
Carl A. Moore, V. E. Monnett, F. A. Melton
Robert Harrell Griffin, Cincinnati, Ohio
John L. Rich, Gordon Rittenhouse, George A. Thiel
Rolla Eugene Hargraves, Midland, Tex.
Fay Coil, A. L. Repecka, R. L. McFall
William Conrad Henkes, Craig, Colo.
A. N. Murray, H. T. Morley, W. S. McCabe
William Jack Holbert, Houston, Tex.
S. A. Lynch, Frederick A. Burt, Harold Vance
Joseph Maxfield Jones, Whittier, Calif.
W. D. Keller, J. T. Richards, Donuil H.Hillis
Ted Richard King, Norman, Okla.
V. E. Monnett, Charles E. Decker, Robert H. Dott
Robert John Knox, Evansville, Ind.
L. R. Laudon, R. C. Moore, R. C. Cooper
Aksel Norvang, Viborg, Denmark
Albert Gregersen, C. W. Flagler, H. Odum
John Chambers Osmond, Jr., Havertown, Pa.
Henry A. Ley, Ford Bradish, David Donoghue

Donald Elmer Outlaw, Austin, Tex.
Hal P. Bybee, F. L. Whitney, G. K. Eifler, Jr.
Carol Lucile Pearson Midland Tex.
V. W. Rogers, R. C. Spivey, A. S. Warthin, Jr.
Raymond Oscar Planteroth, Mt. Pleasant, Mich.
K. E. Adams, V. C. Scott, Jack Hirsch
Wesley Waltrip Rees, Dallas, Tex.
Paul E. Nash, J. C. Menefee, Henry C. Cortes
Milton Richard Scholl, Jr., Houston, Tex.
Fred M. Bullard, F. L. Whitney, G. K. Eifler, Jr.
John Warren Skrabanek, Austin, Tex.
L. C. Snider, Fred M. Bullard, G. K. Eifler, Jr.
James Richard Story, Midland, Tex.
Leonard Latch, Philip D. Larson, L. E. Patterson, Jr.
David R. Toland, Roosevelt, Utah
S. Zimerman, W. J. Lang, Robert Paterson
Henry William Volk, Jr., Houston, Tex.
E. J. Barragy, George A. Thiel, Clinton R. Stauffer
Holly Clyde Wagner, Los Angeles, Calif.
James Gilluly, Cordell Durrell, W. C. Putnam
William Harry Wallace, Jr., Corpus Christi, Tex.
Shepard W. Lowman, Henry V. Howe, Chalmer J. Roy
Victor Hubert Zoller, Shreveport, La.
E. A. Taegel, W. H. Butt, Milton W. Corbin

FOR TRANSFER TO ACTIVE MEMBERSHIP

Leslie Winston Dorbandt, Wichita Falls, Tex.
Robert Roth, D. D. Heninger, John A. Kay
Thomas Stephens Gandy, San Antonio, Tex.
Robert N. Kolm, A. H. Alcorn, W. Dow Hamm
Robert Paul McNeal, Wichita, Kan.
T. C. Peters, John W. Inkster, Clinton Engstrand
Mary Louise Rhodes, Midland, Tex.
H. A. Ireland, R. V. Hollingsworth, H. L. Burchfiel
Delmar Oscar Branson, Tyler, Tex.
Ray F. Youngmeyer, R.M. Trowbridge, L. S. Melzer
Silas Christian Brown, Phoenix, Ariz.
Bruce F. Latta, Wallace Lee, John C. Frye
Frederic L. Burchard, Dallas, Tex.
Willis G. Meyer, Louis C. Roberts, Jr., Lewis W. MacNaughton
Jack Overton Colle, Houston, Tex.
Hershal C. Ferguson, W. Z. Burkhead, W. A. Reiter
Lee Henri Cornelius, Tulsa, Okla.
Fred A. Devin, Myron C. Kiess, G. A. Northrip
Jack Francis Dougherty, Dallas, Tex.
John H. Murrell, H. J. Gruy, Sidney A. Packard
Francis A. Douglass, Jr., Midland, Tex.
George R. Gibson, W. A. Waldschmidt, Ronald K. DeFord
Wilbert Lawrence Falconer, Calgary, Alta, Canada
F. A. McKinnon, Douglas B. Layer, W. P. Hancock

John Robert Gisburne, Oklahoma City, Okla.
John E. Galley, Robert B. Wing, J. B. Leiser
Louis Howard Haring, Jr., San Antonio, Tex.
H. E. Menger, Donald F. Sandifer, M. A. Harrell
Donald Grant Herring, Jr., Jackson, Miss.
Robert E. King, William W. Moore, Jr., Harry X. Bay
Melvin James Hill, Bakersfield, Calif.
Glen W. Ledingham, R. Stanley Beck, R. W. Clark
Jack Newton Huff, Wichita Falls, Tex.
M. W. Sherwin, John N. Berg, Grover E. Murray, Jr.
Richard John Hughes, Jr., Austin, Tex.
Hal P. Bybee, G. K. Eifler, Jr., Don L. Frizzell
Robert Morris Hutchins, Jr., Lake Charles, La.
Frank Bruner, Carl L. Larson, Jr., W. B. Neill
William Eric Kennett, Santa Maria, Calif.
Art R. May, R. B. Hutcheson, Edward C. Simpson
Eldon Woodrow Langford, Levelland, Tex.
L. C. Snider, Hal P. Bybee, Frank Ittner
James Edward Lewark, Mattoon, Ill.
Lee C. Lamar, Robert M. English, Wade W. Turnbull
Frederic Brewster Loomis, Jr., Lake Charles, La.
C. L. Herold, James B. Dorr, Stanley R. Say
Robert Scott Mann, San Antonio, Tex.
Ernest Guy Robinson, F. A. Nelson, Leo R. Newfarmer
Atlee George Manthos, San Antonio, Tex.
Robert N. Kolm, Willis Storm, Ed. W. Owen
Jay Glenn Marks, Stanford University, Calif.
John C. Hazzard, Siemon W. Muller, A. I. Levorsen
Charles Leonard Matthews, Wellington, Kan.
L. W. Kesler, R. C. Cooper, Charles W. Honess
Marlowe Douglas Melvin, Mattoon, Ill.
Lee C. Lamar, Robert M. English, Wade W. Turnbull
John Man Morgan, Houston, Tex.
Ralph G. Nichols, Harold E. Voigt, M. A. Reasoner
John Barratt Patton, Mt. Vernon, Ill.
Fred H. Moore, W. W. Hammond, John R. Sandidge
Raymond Elliott Pearson, Long Beach, Calif.
M. L. Natland, W. T. Rathwell, Jr., Rodman K. Cross
Finis Mack Samford, Tyler, Tex.
E. A. Wendlandt, T. J. Burnett, T. H. Shelby, Jr.
Fred M. Schall, Jr., New Orleans, La.
M. N. Broughton, B. E. Bremer, G. W. Schneider
Arvin Forrest Scott, San Antonio, Tex.
R. E. Bonar, Paul B. Hinyard, C. G. Dickinson
E. Bruce Shade, Findlay, Ohio
Robert G. Kurtz, Fred J. Funk, Stanley B. White
Edward Cramon Stanton, Jr., Charleston, W. Va.
Robert C. Lafferty, A. Y. Barney. H. J. Simmons, Jr.
Frank V. Stevenson, Bogota, Colombia, S. A.
Carey Croneis, A. N. Murray, R. V. Hollingsworth

Glen C. Thrasher, Denver, Coo
John Marshall, A. J. Crowley, H. E. Christensen
Louis Herman Weltman, Jackson, Miss.
Gilbert A. Talley, Jules Braunstein, M. W. Sherwin
Albert William White, Wichita Falls, Tex.
T. F. Petty, Paul E. M. Purcell, Charles P. McGaha
Frank Thomas Whittinghill, Jr., Robinson, Ill.
L. A. Mylius, J. H. Poteet, J. Albert Brown

JOINT ANNUAL MEETING, BILTMORE HOTEL, LOS ANGELES, MARCH 24–27

HAROLD W. HOOTS[1]
Los Angeles, California

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

EXECUTIVE COMMITTEE

Earl B. Noble, President
Monroe G. Cheney, Past-Pres.
D. Perry Olcott, Vice-Pres.
Ed. A. Koester, Secy.-Treas.
Gayle Scott, Editor

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

COUNCIL

F. W. Rolshausen, President
John R. Sandidge, Past-Pres.
Cecil G. Lalicker, Vice-Pres.
Henryk B. Stenzel, Secy.-Treas.

SOCIETY OF EXPLORATION GEOPHYSICISTS

EXECUTIVE COMMITTEE

J. J. Jakosky, President
Henry C. Cortes, Past-Pres.
Cecil H. Green, Vice-Pres.
Geo. E. Wagoner, Secy.-Treas.
L. L. Nettleton, Editor

PACIFIC SECTION OFFICERS

Martin Van Couvering
President

W. P. Winham
Vice-President

C. W. Johnson
Secretary-Treasurer

CONVENTION ARRANGEMENTS

Harold W. Hoots
General Chairman

Howard C. Pyle
General Vice-Chairman

COMMITTEE CHAIRMEN

Robert W. Clark
Technical Program
C. R. McCollom
Reception
John C. Hazzard
Field Trips

Vincent W. Vandiver
Hotels and Housing
E. R. Atwill
Entertainment
H. J. Steiny
Transportation

Vernon L. King
Registration
Gordon Bell
Publicity
Herschel Driver
S.E.P.M.

John R. McMillan
Finance
W. P. Winham
Exhibits
Eugene H. Vallat
Henry Salvatori
S.E.G.

[1] General chairman, convention arrangements.

ANNOUNCEMENT

The 32d annual meeting of the American Association of Petroleum Geologists will be held at the Biltmore Hotel, Los Angeles, California, on March 24–27, 1947. The 17th annual meeting of the Society of Exploration Geophysicists will be held on March 25–27, and the 21st annual meeting of the Society of Economic Paleontologists and Mineralogists, will be held on March 26 and 27. A cordial invitation is extended by the Pacific Section to all Association and Society members and their wives.

ATTENTION PLEASE

Information from returned post-cards as to certain and probable attendance at the Los Angeles convention in March, 1947, indicates an unusually large attendance for a California meeting—50–100 per cent larger than in 1937. This is gratifying to your executive committee, your convention committee, the Pacific Section, and particularly to the tough and hard "Old Guard" members of the Association. Such attendance will demonstrate clearly to these groups that you consider these annual conventions worth-while, that you like to come to one held in California, and that our membership is still composed of hardy men who, when in quest of additional knowledge, will knowingly subject themselves to almost any hardship—and return home with a grin.

Ten years ago—back there in 1937—the Biltmore Hotel urged us to take full advantage of their 1,500 rooms to house our visiting members and guests, and to accept *gratis* all space needed for technical sessions, committee meetings, and exhibits. Those were the days when California was called the land of free milk and honey. To-day, after much maneuvering on both sides, the Biltmore allows us a total of 250 rooms for an anticipated attendance of 1,500–1,800 and charges us $2,000 for the meeting rooms essential to our convention. Since the Biltmore will be housing only one out of every four or five person attending the convention, all responsibility for your reservation, assigning you to a hotel, obtaining the required advance deposit, and confirming your reservation must be handled by our hotel and housing committee. This local committee is eager to do a good job. Its one big hope is that the 75–80 per cent of attending members and guests who do not obtain reservations at the Biltmore Hotel will be those hardy folk with the characteristic grin. California members needing reservations will be assigned to hotels other than the Biltmore.

An excellent technical program, instructive field trips, and plenty of opportunity for entertainment will combine to make this a good meeting.

A modest registration fee will be charged to assist in defraying the costs of this convention.

TECHNICAL PROGRAM

The technical program is designed to present and explore problems encountered by those engaged in petroleum exploration in lands adjacent to the Pacific Ocean. It will be initiated Monday evening with a discussion of sedimentation in the small, deep basins such as are found on the Pacific Coast. Manley Natland will describe a condition in the Los Angeles Basin in which deep-water fauna are found at the edge of deposition in the Puente sea. This paper is to be followed by K. O. Emery's discussion of "Patterns of Sedimentation on the Continental Shelf off California." This theme will be pursued further on Tuesday afternoon by a series of papers on California in which Harold W. Hoots will first picture the general geological situation and its relation to the development of the petroleum industry. Then there will be three papers on the genesis and evolution throughout Tertiary time of "The Los Angeles Basin" by Herschel Driver; "The Ventura Basin" by Thomas L. Bailey; and "The Great Interior Valley" by Glenn H. Ferguson.

The Tuesday morning session will provide the formalities of the opening of the annual meeting, including the presidential addresses and various awards. Two important papers

will also be presented at this session. K. C. Heald will give a running account of the highlights of domestic developments in 1946 and L. G. Weeks will treat foreign developments in the same manner. The geophysicists will hold a separate technical session in the afternoon. A paper on "The Petroliferous Provinces of Washington and Oregon" will wind up the day's program.

Wednesday will be devoted to discussions of the geology of lands bordering the Pacific. Professor Walter H. Bucher will set the stage for this with his discussion of the "Geologic Framework of the Pacific." This will be followed by papers on China by Carlton D. Hulin; The Philippines by Grant W. Corby; Japan by Charles W. Chesterman; Petroleum Production and Resources of Japan by David Cerkel and J. L. Williams; New Zealand by Frank Turner; Central America by Wendell P. Woodring; Eastern Peru and Ecuador by Bernhard Kummel; Coastal Oil Fields of Peru by A. Lyndon Bell; and Chile by Glen M. Ruby. A paper by L. G. Weeks, entitled "Paleogeographies of South America," will be on the Wednesday program. The geophysicists are planning no separate technical session on Wednesday but are providing two and possibly three papers to be presented Wednesday morning at the combined session. These will be of equal interest to geologists and geophysicists. One of them is "Geophysical Work in the East Indies" by O. F. Van Beveren. The paleontologists will hold separate technical sessions in both morning and afternoon.

Overthrusting is a condition met very frequently and in widely separated areas by geologists in Pacific regions. Wednesday evening is to be dedicated to this problem. Theodore A. Link will guide the symposium and lead off with a discussion of overthrusting in Alberta. Edward C. H. Lammers will discuss overthrusting along the Santa Clara Valley in California where many oil fields exist both above and below the thrust planes, and Donald LeRoy Blackstone, Jr., will discuss overthrusting in Rocky Mountain petroliferous provinces.

Thursday will be devoted to domestic, descriptive, and development papers. Already a number of these have been arranged through the aid of the publications committee with its widespread membership and their resultant familiarity with interesting developments and the men best qualified to present them. There will be a variety of papers from Texas, Louisiana, Florida, Oklahoma, New Mexico, the Rocky Mountain states, and others. The paleontologists will hold a symposium on "Sedimentary Lithology" in the morning, and the geophysicists will hold technical sessions all day Thursday.

GENERAL OUTLINE OF PROGRAM

Sunday, March 23	A.A.P.G. Research Committee meeting.
Monday, March 24	Joint Registration and Committee Meetings.
Night.	Open Session. Tertiary and Recent Sedimentation, a Symposium.
Tuesday, March 25	
A.M.	Joint Session. Presidential addresses and awards; Reviews.
P.M.	A.A.P.G. California petroliferous basins.
P.M.	S.E.G. Business Meeting and technical session.
Wednesday, March 26	
A.M.	Joint Session. Geology of foreign lands bordering Pacific.
	A.A.P.G. Business Meeting
	S.E.P.M.—A.M. California stratigraphy.
	P.M. General Paleontology.
Night.	Open Session. Thrust Faulting Symposium.
Thursday, March 27	
	A.A.P.G. Geology and development papers Mid-Continent, Gulf Coast Rocky Mountains.
	S.E.P.M.—A.M. Symposium on sedimentary lithology.
	S.E.G. Technical sessions.
Night.	Dinner-dance.

FIELD TRIPS

1. Chester Stock, of the California Institute of Technology, will conduct a field trip to the La Brea Fossil Pits and the Los Angeles Museum on the afternoon of Monday, March 24.

2. The Society of Exploration Geophysicists is planning a trip to the California Institute of Technology and its Seismological Laboratory in Pasadena on the afternoon of Wednesday, March 26.

3. A post-convention field trip is scheduled to leave 9 A.M., Friday, March 28, returning to Los Angeles late Sunday afternoon, March 30. The first day will cover structural and stratigraphic features of the Aliso Canyon field, the Santa Clara Valley, and the Ventura Avenue field. Those desiring to return to Los Angeles at the end of the first day's tour may do so from Ventura.

Friday night will be spent at Santa Maria. Saturday morning the Santa Maria area will be studied and in the afternoon the party will leave for Bakersfield *via* the Cuyama Valley; the San Andreas rift and the Midway-Sunset district will be viewed *en route*. Saturday night will be spent at Bakersfield. On Sunday, fields of the west side and central part of the southern San Joaquin Valley will be visited and the return trip to Los Angeles will be made *via* the Ridge Route.

Transportation costs for the three-day trip will be prorated and paid by each person attending. In view of transportation requirements and the limited hotel accommodations in both Santa Maria and Bakersfield it is absolutely essential that firm reservations be made by those planning on this trip. Those interested in this post-convention field trip should not fail to indicate their wishes on the reservation form.

EXHIBITS

Desirable advertising space for exhibits of equipment, maps, and services used in petroleum exploration is available in the Foyer, at the entrance to the technical meetings. Parties interested in purchasing space and arranging for exhibits should write immediately to W. P. Winham, 605 West Olympic Boulevard, Los Angeles, California.

ENTERTAINMENT

The dinner-dance in the Biltmore Bowl on Thursday night and the ladies tea on Tuesday afternoon constitute the only planned entertainment on the program.

Tuesday night, with no technical meeting, is available for those who wish to plan entertainment. Those desiring assistance in obtaining reservations for The Drunkard (lots of fun) for Tuesday night, or for Earl Carroll's Night Club or the Cocoanut Grove (Ambassador Hotel) for Tuesday or other nights, should so indicate on the enclosed reservation form

LADIES ENTERTAINMENT

Entertainment for visiting ladies is being planned by a local group under the leadership of Mrs. Carroll M. Wagner. A tea, sponsored by Mrs. Earl B. Noble, will be held at the Avila Adobe in Calle Olvera at 3:00–5:30 Tuesday afternoon, March 25. All ladies are cordially invited. The Avila Adobe is the oldest house in Los Angeles and one of the historic spots of Southern California. Its setting in the midst of old Spanish Los Angeles will be pleasing to those who still can imagine being stirred to romance by Spanish music and a gay Caballero.

Other entertainment for ladies will be provided in accordance with existing facilities and the indicated wishes of those who plan to attend. Herewith is a list of events which,

according to present tentative plans, will be available within limits. The indication of your wishes on the reservation form will necessarily constitute a reservation, and will serve as the basis of definite arrangement. You will be requested to purchase your tickets when you register upon arrival at the convention.

Event	*Time*	*Cost*
Broadcast "Queen for a Day"	Thursday 11:30 A.M.	None except lunch
Sightseeing trip of City, studios, and Westwood Village with lunch at the beach	Wednesday all day	$7.50
The Turnabout Theater	Wednesday evening	$2.40

HOTELS AND HOUSING

The hotels and housing committee has obtained commitments for comfortable rooms from sixteen of the better and most conveniently located hotels. These commitments may be converted into definite reservations only to the extent that those expecting to attend meet the requirements indicated herein.

Fill out your reservation form, attach your personal check required by the hotel as an advance deposit for your room, and mail on or before February 25. Checks for $5.00 per person should be made payable to V. W. Vandiver, Hotels Chairman. Hotel reservations to be handled by the hotels and housing committee will close on March 1.

Those who can and wish to stay in private homes are encouraged to do so.

Try to avoid requesting a single room. If possible, team up with somebody else and request a double room.

Your arrival on Sunday, March 23, will save you much confusion and will relieve the inevitable congestion expected on Monday, March 24.

	All Rates Subject to Change
Biltmore (Headquarters)	$4.50 and up, Single $6.50 to $10.00, Double
Alexandria	$5.00 to $7.00, Double (1 bed) $6.00 to $7.00, Double (Twin beds) $7.00 to $8.00, Triple (3 beds) $7.00 to $8.00, Triple (2 beds)
Ambassador	No rates quoted
Chapman Park	No rates quoted (All Twin beds)
Clark	$6.00 to $8.00 daily
Commodore	$2.50 to $3.50 daily
Embassy	$3.00 to $4.00 daily
Figueroa	$3.50 daily (All Twin beds)
Hayward	$3.50, Single $5.50, Double
Lankershim	$3.85 to $5.50 (All Double and Twin beds)
Mayfair	$3.85 daily (Twin beds)
Rosslyn	$4.00 to $6.00 (Double and Twins) $4.50 to $7.00 (Triples)
San Carlos	$4.00 daily, Single or Double
Stillwell	$3.00 to $4.00 daily
St. Paul	$3.00 to $4.00 daily
Teris	$3.00 to $4.00 daily
Town House	Approximately $18.50 daily

Correspondence addressed to any of the foregoing hotels will be referred directly to our hotels and housing committee.

Those who prefer auto courts, or hotels other than those listed, are privileged to write at once directly to these establishments for reservations.

Desirable Motor Hotels	*Address*	*Comments*	
El Adobe Motel (Attention Mr. Nelson, Mgr.)	800 W. Garvey Monterey Park	Have several apartments requiring 3 or 4 persons; $3.00 per person.	
Deposit for one day required 15 days in advance.			
Pueblo de Los Angeles	1750 Colorado Blvd. Eagle Rock 41, California	Cottages with double beds	
		Single (2 persons)	$ 5.00
		Double (4 persons)	$ 8.00
		Triple (6 persons)	$13.00
1 day deposit required 3 weeks in advance.			
Alberts Motel	1460 Colorado Blvd., Eagle Rock 41, California	Room for two	$3.00
		Room for three	$4.00
		Room for four	$8.50
1 day deposit required 30 days in advance.			
Grand Motel (Mrs. Smock, Mgr.)	3321 East Colorado Blvd., Pasadena	Room for two	$2.00
		Room for three	$3.00
		Room for four	$4.00
1 day deposit required 30 days in advance.			

All quoted rates for hotels and motor hotels are subject to increase in the immediate future.

Each member was mailed a copy of this announcement, with reservation blank, in the early part of February.

Following is only a copy of the reservation form which was mailed separately to each member early in February. The member is to return that form in a specially marked envelope to Vincent W. Vandiver, Seaboard Oil Company, 417 South Hill Street, Los Angeles, California.

SAMPLE RESERVATION FORM

Read your announcement,
Fill out and return this form
for
YOUR RESERVATIONS

IMPORTANT: Mail this form with your check on or before February 25, 1947.

FOR YOUR HOTEL ROOM

I request ______________________________ at ________________ Hotel
(Number and type of rooms; double or twin beds) (Preference)

March ______________________________. Sharing this room with me will be
(dates)

____
(Give name of other person or persons)

I (we) arrive on ________________ at ______________ March ______________;
(Railroad) (Hour) (date)

my check for $______________ is attached.
($5.00 per person)

NOTE: Your reservation and attached check must be received by the committee by March 1. 1947. You should receive confirmation of your reservation and name of hotel by March 15.

For Field Trips

I wish to attend the following field trips:	*Check below*
1. Rancho La Brea Fossil Pits and Museum (Monday, March 24)	________
2. California Institute of Technology and its Seismological Laboratory (Geophysicists, Wednesday, March 26)	________
3. Ventura, Santa Barbara, Santa Maria, Bakersfield, Los Angeles (March 28–30)	
(a) To Ventura and return Los Angeles (Friday, March 28)	________
(b) Complete trip (arriving Los Angeles, Sunday evening, March 30)	________

For Entertainment

General Entertainment

Dinner-Dance (Thursday night)—tickets should be purchased and tables should be reserved when you register.

The Drunkard show—Please arrange ________ reservation(s) for me ($2.50 each) for Tuesday night.

Cocoanut Grove (Ambassador Hotel)—Please arrange ____________ reservations for me for ______________ night (dinner and essentials $6.00–$7.00 per person).

Earl Carroll's Night Club—Please arrange ________ reservation(s) for me for ____________ night (average total cost $10.00 per person).

Ladies Entertainment

Ladies Tea—Tuesday 3:00–5:30 P.M. Sight-Seeing Trip (Wednesday)—Please make ________ reservation(s) for me ($7.50 each).

"Queen for a Day" Broadcast (Thursday). Please make ________ reservation(s) for me ($2.40 each).

The Turnabout Theatre (Wednesday night)—Please make ________ reservation(s) for me ($2.40 each).

Special Train From Houston

The Houston Geological Society is sponsoring a deluxe special train to the annual convention, leaving Houston over the Santa Fe system Thursday, March 20, at approximately 9 P.M., and arriving in Los Angeles Sunday, March 23, at 10:00 A.M. Members from South Louisiana and Mississippi will board the train at Houston. Special cars from other points in Texas will be picked up *en route*. A printed itinerary giving detailed schedules of trains making connection with the special will be mailed to all members living in Louisiana, Mississippi, and Texas.

Most of Saturday, March 22, will be spent in the vicinity of the Grand Canyon with an optional trip along the rim. A lecture by the National Park geologists will be given during the stop.

No special train will be run on the return trip, and those making the return trip may do so by Santa Fe or by Southern Pacific *via* El Paso. San Francisco may be included in the round-trip fare for approximately $15 additional. Return from San Francisco may be made *via* Royal Gorge or Moffat Tunnel by any number of routes at approximately the same cash as returning from Los Angeles.

It is suggested that those receiving the printed itinerary discuss with their local ticket agents their route of return. A round-trip ticket from Houston and return including lower berth and federal tax will cost approximately $136. Compartment and drawing-room accommodations will be slightly higher. Fares from all principal points will be quoted in the printed itinerary to be mailed at an early date.

This Transportation Committee has no connection with the Los Angeles Hotel Reser-

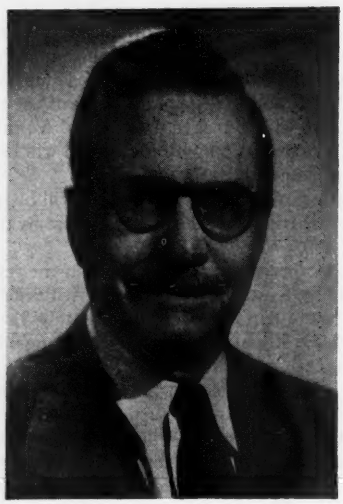
A.A.P.G. OFFICERS-ELECT

(TERM OF OFFICE TO BEGIN AT END OF ANNUAL MEETING, MARCH, 1947)

PRESIDENT C. E. DOBBIN

VICE-PRESIDENT GEORGE S. BUCHANAN

SECRETARY-TREASURER J. V. HOWELL



EDITOR C. L. MOODY

vation Committee. Individual members should continue to make Los Angeles hotel reservations through Vincent W. Vandiver, Seaboard Oil Company, Room 970, 417 South Hill Street, Los Angeles, California.

Houston Transportation Committee
CARLETON D. SPEED, JR., *chairman*
F. W. MUELLER, Rutherford Drilling Company
B. F. MORGAN, Stanolind Oil and Gas Company

COOPERATION AMONG GEOLOGICAL SOCIETIES, AND AMERICAN GEOLOGICAL INSTITUTE

C. L. CAMP AND W. B. HEROY

NATIONAL RESEARCH COUNCIL, Washington, D. C.
November 18, 1946

To the President and Secretary,
The American Association of Petroleum Geologists,
Box 979,
Tulsa 1, Oklahoma

Gentlemen:

At the joint invitation of the Geological Society of America and of the Division of Geology and Geography, National Research Council, your organization appointed delegates to attend an assembly of representatives of geological societies, to be held in Washington, D. C., on October 12–13, 1945, "at which problems of common concern to all geological societies could be discussed and plans laid for future joint activities."

At this assembly, which was attended by representatives of thirteen organizations, the need for cooperative effort among geological societies was discussed fully and it was the sense of the meeting "that there are sufficient needs to justify an organization or a cooperative effort in order to accomplish them."

In order that the views of the assembly might be presented to the participating societies and made known to their members, two committees were appointed to prepare statements; (1) concerning the needs for closer cooperation among geological societies, and (2) concerning the proposed "American Geological Institute." These committees, under the respective chairmanships of C. L. Camp and W. B. Heroy, prepared reports which have now been reviewed by the delegates of all the societies represented. With their approval, copies of the final statements are presented herewith for your consideration. The assembly suggested that the participating societies make these statements available to their members.

C. L. CAMP, *chairman*
Committee on Needs for Cooperation

W. B. HEROY, *chairman*,
Committee on Proposed American Geological Institute

W. W. RUBEY, *chairman*,
Assembly of Representatives of Geological Societies,
Then chairman, Division of Geology and Geography, National Research Council

ARTHUR BEVAN, *present chairman*,
Division of Geology and Geography, National Research Council

STATEMENT CONCERNING NEEDS FOR CLOSER COOPERATION AMONG GEOLOGICAL SOCIETIES

It has been proposed that the various geological societies and organizations of the United States and Canada should band together in order to strengthen themselves, to work more effectively. and to carry their services into new channels. Such a federation should serve to increase the power and effectiveness of geology for the people and the government. Professional geologists and their associates should benefit by such cooperation.

Unity among diverse groups is desirable if certain programs and policies are to be undertaken. Goodwill and fellowship should be promoted, and mutual understanding.

The federated societies should assist each other in their various programs. They should not encroach on prerogatives or hinder the free initiative of member societies. Together they would accomplish much that is beyond the present means of member groups, for they would operate in fields not now adequately covered.

Duplication of effort would be forestalled, formation of new groups would be facilitated, special fields now neglected could be cared for, matters of public interest would receive attention. For geology should be able to serve more effectively in public affairs.

A federation has been proposed and a tentative constitution drawn up under the name: American Geological Institute. This constitution should prove generally acceptable to most of the geological groups. Membership would be confined to organizations in the fields of research and applied geology in the broadest sense. No individual could become a member. Control of the organization would rest in the societies themselves, with proper safeguards to prevent control from passing to any one section of the membership.

A statement of needs not now adequately covered is the function of this committee. A further statement of the means of caring for such needs will be offered by Mr. Heroy's committee.

DISCUSSION OF NEEDS

I. IMPROVEMENT OF PUBLIC RELATIONS

Public relations progams should be more effectively coordinated. Popular, elementary college courses, sporadic high school and museum activities, an occasional radio broadcast, magazine or newspaper article, furnish examples of what has been done. Liaison with the amateurs, especially the mineralogical societies, would seem to be advantageous. Stimulation of publication of well written popular articles and books is another possible line of attack. Organization of lectures and guide books for National Parks, travel routes, local areas of interest are possibilities. A geological magazine of popular appeal has also been suggested.

II. IMPROVEMENT OF GOVERNMENTAL RELATIONS

Committees and advisory groups appointed to counsel with governmental bodies and demonstrate to them the value of applied studies should have strong backing from professional geological groups. Cooperation in engineering and public works projects, soil conservation, dust and flood control, the military field, and many other federal enterprises is highly important.

Furthermore, the federation would undertake to keep its membership fully informed as to pending legislation on matters of concern to geologists.

III. IMPROVEMENT OF INDUSTRIAL RELATIONS

The petroleum industry has come to appreciate the value of geology. The mining industry is probably a close second. But there is much contact work to be done in other fields, particularly in engineering construction projects involving extensive excavations as in dams, tunnels, and foundations. A central information bureau where all can come to seek advice is obviously needed.

A further need is to encourage publication of the results of industrial work, which all too often get buried in the files.

IV. IMPROVEMENT OF PROFESSIONAL RELATIONS

Some of our ablest teachers have been leaving their classrooms for more lucrative fields. This migration may become serious enough to hamper training and halt the flow of students. A survey of teachers' needs, salaries, equipment, opportunity for travel, field work and research, also scholarships and funds for their problems would seem desirable. Teaching institutions should be consulted and advised as to adequacy of curricula, and teaching standards should be guarded by proper accrediting of teachers, as well as in-

stitutions. Liaison between academic and industrial circles should be fostered by interchanges of ideas and personnel.

Professional as well as governmental and industrial groups should find use for service record indices. An up-to-date personnel roster might be maintained, starting with the list now in preparation by the G.S.A. particularly if the National Roster of Scientific and Specialized Personnel is to abandon its project after 1946. Reports and information on selective service might be circulated. Maintenance of an employment bureau has been suggested, also the frequent cataloguing and publishing of information on current research projects, mapping projects, industrial programs, Federal, State and organizational activities, lists of recent publications, maps, aerial photos, and new technical apparatus and methods.

Local geological organizations should find it helpful to call upon some central organization for service and advice. It may have the duty of cooperating with regional surveys, local mining bureaus and local academies, by interchange of literature, distribution of announcements of meetings, consultation on programs, and encouragement of local mapping projects.

Periodic conferences of secretaries of geological organizations as well as publication of a descriptive annual of societies have been suggested.

V. STIMULATION OF RESEARCH

Solutions to many practical and theoretical problems have come by integrating the results achieved in diverse branches of science. Geology has its relations with biology, anthropology, geography, oceanography, chemistry, physics, and astronomy. Survey of possibilities for discovery of new methods and new uses for the results of research in outlying fields might be a part of the program, it being understood that much of such work so far has been done effectively by existing societies.

Survey of current geological research programs will doubtless reveal some overlapping and duplication. Not all of this may be undesirable but some of it wastes money and time. A research record bureau might be an answer to this problem.

While the proposed federation would presumably not expect to engage directly in support of research on any large scale, it might assist established bodies such as the Geological Society of America and the National Research Council in coordinating and formulating plans for research—particularly in cooperative projects.

It is further suggested that joint meetings of societies be held under sponsorship of the proposed federation or under invitation of major existing societies.

May 9, 1946

C. L. Camp, *chairman*
Ira H. Cram — Paul F. Kerr
Carey Croneis — Chester W. Longwell

STATEMENT CONCERNING PROPOSED "AMERICAN GEOLOGICAL INSTITUTE"

The American Geological Institute is a proposed organization the members of which would be associations and societies of national scope that are active in the field of geology. Individuals would not become members of the Institute. "Geology" is used in a broad sense, the equivalent of "earth science," and the member organizations may be concerned with pure or applied science.

A constitution for the Institute was drafted in New York City on October 22–23, 1944, in a meeting in which eight societies were represented. An invitation to become members of the Institute by adoption of this constitution was sent to eleven eligible societies. The constitution provides that other non-profit national organizations active in the field of "geology" may be admitted to membership, and it is hoped that the eligible organizations will choose to become affiliated.

The purpose of the institute is to advance "geology" in all its aspects by providing an agency through which the member organizations can cooperate on a definite and permanent basis. This purpose is expressed in the constitution in the broadest terms in order that the cooperative activities may include any specific objectives that the constituent organizations may consider desirable. It is intended that the Institute shall engage in those cooperative activities which the member organizations are not in a position to undertake individually. The Institute may promote any new activity for the advancement of "geology" and arrange that it be carried out jointly by the member societies or by any member organizaton best suited to perform it. Some desirable objectives that might be reached most effectively through cooperative effort are the improvement of relations with the public, the advancement of the study of geology in relation to government, the coordination of publications, the accrediting of geological curricula, and the stimulation of research. But, most important of all, an organization will be created which will represent "geology"as a whole and which will truly express the geological concensus.

The machinery by which the Institute would operate has been designed to be as simple as possible, consistent with the effective performance of its functions. Each member organization will designate two Directors who will, after the initial period, serve for two-year terms, one Director being elected each year. These Directors will choose annually three Directors-at-large. The entire group constitutes the Board of Directors, in which the control and management of the Institute's affairs are vested. The Board will meet annually to elect officers, appoint committes, manage finances, and make suitable regulations for the conduct of the affairs of the Institute.

The officers of the Institute will consist of a President, a Vice-President, and a Secretary-Treasurer, all elected annually, who will perform the customary duties and who together will constitute the Executive Committee. The Executive Committee will act between meetings of the Board to carry on such business as the Board may authorize or direct. With the prior approval of the Board, the Executive Committee may establish a headquarters for the Institute and employ qualified personnel.

The Institute will become operative upon ratification by seven societies. Provision is made for the amendment of the constitution. Any member organization may withdraw from membership at any time upon written notice. No financial obligation whatever is incurred by any member organization because of membership in the Institute. It is believed desirable that the Institute be incorporated, in due course, in order to protect the non-profit status of the member organizations, to divest the member societies as well as the Directors personally of legal liabilities, and to make more effective operation of the Institute possible. No specific provision has been made in the constitution for the financing, of the operations of the Institute. The initial organization of the Institute can be effected with very moderate expense. The expenses will remain moderate until the Board of Directors develops projects calling for substantial expenditures. At that stage, the problem of procurement may be delegated to appropriate committees. Once the Institute has demonstrated its value, substantial contributions from foundations and industrial organizations interested in the advancement of geologic science become possible.

It is clear that the proposed Institute would operate through the common consent of the member organizations, each acting through its designated Directors. The need for an organization for cooperative effort among geological societies was recognized by the informal assembly of representatives in Washington convened October 12–13, 1945. It is the opinion of the proponents of the American Geological Institute that it represents the best solution of the problem of effective cooperation.

April 8, 1946

W. B. Heroy, *chairman*

Ira Cram — C. R. Longwell

Carey Croneis — W. T. Thom, Jr.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 421-422, 1 FIG.

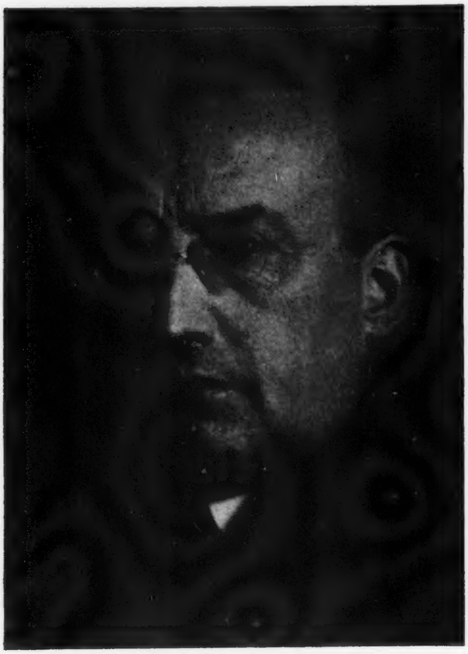
MEMORIAL

WALTER BERNOULLI

(1885–1946)

A sudden heart attack on December 8, 1946, took Walter Bernoulli away from his family and his many friends, and set an end to his work as president of the board of directors and head of the geological department of the Museum of Natural History in Basle, Switzerland.

Walter Bernoulli was born on the 23rd of May, 1885, in Basle. He studied geology at the universities of Basle and Vienna and obtained his doctor's degree at Basle in 1912.



WALTER BERNOULLI

He then went overseas in the services of several oil companies, first to India, later to the Balkans, Africa, Venezuela, North America, and Iran. He became a member of the American Association of Petroleum Geologists in 1924.

In 1931 Dr. Bernoulli married Miss Emmy Geiger and founded his home in Basle. He begun to devote most of his time to the scientific societies and institutions of his home town and of Switzerland at large. During seven years he was the editor of the *Eclogae Geologicae Helvetiae*, the publication of the Swiss Geological Society. He also worked on the *Geological Guide through Switzerland* which was published in 1934 by the same society.

From 1934 to 1940 he was a member of the executive committee of the Swiss Society of Natural Sciences in which he held the responsible office of treasurer. In 1942–1943 he presided over the Basle Society of Natural Sciences.

Early in his life Dr. Bernoulli had already taken up connections with the Museum of Natural History in Basle to which he donated most of the collections he brought back from his travels. Thus it was natural that he should become head of its geological department and a member of its board of directors in 1935. There he found a wide field for his talent of organization which is evinced by the excellent display and order of the Museum's large geological collections. In 1941 he became president of the board of directors and was since then responsible for the administration of the Museum. During the war years this was a difficult task, and the possibility of sudden destruction of the valuable collections must have weighed heavily upon him. His death is a great loss for the institution to which he gave so many years of his life.

Dr. Bernoulli is survived by his wife and their two children. He will be remembered by his many collaborators who found in him not only an excellent scientist but a loyal friend.

H. P. SCHAUB

BASLE, SWITZERLAND
December, 1946

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 2 (FEBRUARY, 1947), PP. 423-428

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Appalachian Geological Society, meeting in Charleston, West Virginia, November 18, heard a paper on "Some Legal and Technical Aspects in Present Status of Secondary Oil Recovery in West Virginia, with Special Emphasis on Water Flooding," presented by JOSEPH R. BLACKBURN, oil and gas division engineer, West Virginia Department of Mines.

ROBERT B. AUSTIN, formerly of Wichita, Kansas, is a development geologist for the California Company in Brookhaven, Mississippi.

RAY P. WALTERS, formerly overseas with ACC Rumania, is in the New York office of the Standard Oil Company (New Jersey), 30 Rockefeller Plaza.

EARL M. WOLTERS, formerly of Denver, Colorado, is with the Phillips Petroleum Company, Bartlesville, Oklahoma.

BETHEA A. MARTIN, formerly of Beaumont, Texas, is in the geological department of the Creole Petroleum Corporation, Apartado 889, Caracas, Venezuela.

REGINALD W. HARRIS, formerly in Jackson, Mississippi, with the Phillips Petroleum Company, may now be addressed at Box 856, Norman, Oklahoma.

A. VAN DEN HOEK has moved from Rotterdam, Netherlands, to Maracaibo, Venezuela, where he may be addressed in care of the Caribbean Petroleum Company.

ALFRED H. BELL, head of the Oil and Gas Division, Illinois State Geological Survey, Urbana, has been appointed to the research and coordinating committee of the Interstate Oil Compact Commission.

The South American Geologic Map Committee of the Geological Society of America is asking that all contributors of corrections to the final geologic map or manuscript for the report to accompany the map, be turned in by May 1, 1947. All such material may be sent to George W. Stose, United States Geological Survey, Washington 25, D. C.

DAVID F. BROUSSARD, formerly with the Independent Exploration Company is chief geophysicist for the Yegua Corporation, 2302 Esperson Building, Houston 2, Texas.

JOSEPH E. POGUE, vice-president of the Chase National Bank, recently spoke on the Princeton University Bicentennial program, and discussed the contribution made by the petroleum industry to the administration of natural resources.

EDWARD J. HAMNER spoke before the Gulf Coast Section, A.I.M.E., Houston, Texas, on November 13. His paper was entitled: "A Review of Well Logging Practices."

PAUL T. WALTON, Pacific Western Oil Corporation division geologist, Casper, Wyoming, spoke before the Wyoming Geological Association, December 16, on the subject: "Ellis, Amsden, and Big Snowy Group, Judith Basin, Montana."

NATHAN C. SURBER has left the Carter Oil Company to engage in consulting work. With E. R. SIMS, also a former Carter geologist, he has established the Rocky Mountain Geological Service, with headquarters in Casper, Wyoming.

L. F. S. HOLLAND, consulting geologist of Hollywood, California, is moving his headquarters to Placerville, California.

LEE W. GIBSON, formerly with the Humble Oil and Refining Company, Houston, Texas, is practicing as a consulting engineer, with his office at 650 South Grand Avenue, Los Angeles 14, California.

RICHARD S. BALLANTYNE, JR., is associated with CORNELIUS G. WILLIS, consulting geologist and petroleum engineer, 750 Subway Terminal Building, Los Angeles, California

WILLIAM E. HUMPHREY, formerly employed in Argentina by The Texas Petroleum. Company, is with the Museum of Paleontology, University of Michigan, Ann Arbor.

W. O. THOMPSON spoke on "Late Paleozoic Stratigraphy of the White River Area, Colorado," before the Rocky Mountain Association of Petroleum Geologists, meeting at the Oxford Hotel, Denver, January 17.

H. M. HOUGHTON, formerly at Bow Island, Alberta, Canada, with the Geotechnical Corporation (Canada), may now be addressed at Box 2040, Tulsa 1, Oklahoma.

JAMES S. YOLTON is employed by the Creole Petroleum Corporation in the Temblador district, Caripito, Venezuela. He was formerly on the staff of the Illinois State Geological Survey, Urbana, Illinois.

GEORGE H. WOLF, formerly of Seattle, Washington, is employed by the Keystone Exploration Company, Karnes City, Texas.

SARGENT M. REYNOLDS is employed by Woodward and Reynolds, Taft, California. He was formerly with The Texas Company at Woodland, California.

ROBERT C. PENDERGRAFT, formerly of Little Rock, Arkansas, is attending Oklahoma University, at Norman.

President EARL B. NOBLE visited members of the Rocky Mountain and Mid-Continent regions in December. He spoke at meetings of the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, the Wyoming Geological Association at Casper, the Kansas Geological Society at Wichita, and the Tulsa Geological Society at Tulsa, Oklahoma.

Newly elected officers of the Ardmore Geological Society, Ardmore, Oklahoma, are: president, ROBERT W. KLINE, Sinclair Prairie Oil Company; vice-president, B. W. JAMES, Phillips Petroleum Company; secretary-treasurer, MURRELL D. THOMAS, The Texas Company, Box 539, Ardmore.

EDWARD HUBERT CUNNINGHAM-CRAIG, well known British petroleum geologist, and a consultant to the Burmah Oil Company, died recently at Beaconsfield, England, at age 72. He was credited with the discovery of oil in Turkey in 1940.

JOSEPH A. GOODSON, exploitation geologist for the Pure Oil Company, and his wife and two small children, of Clay City, Illinois, were lost in the Winecoff Hotel fire in Atlanta, Georgia, in December.

DON W. JOPLING, formerly of Ithaca, New York, is employed by Exploration Surveys, Inc., 1914 North Harwood Street, Dallas, Texas.

CHARLES A. MILNER is associated with C. W. TOMLINSON, independent operator and geologist, Ardmore, Oklahoma.

LEROY FISH is a consulting geologist, 2517 Transit Tower, San Antonio, Texas. He was formerly with Petroleos Mexicanos, Nuevo Laredo, Tamps., Mexico.

JAMES P. BOWEN, formerly with the Panhandle Refining Company, has a consulting Office at 605 City National Building, Wichita Falls, Texas.

The San Joaquin Geological Society, on December 10, elected the following officers:. chairman, ARTHUR S. HUEY, Shell Oil Company, Inc., Bakersfield, California; vice-chairman, J. H. MCMASTERS, Honolulu Oil Corporation, Bakersfield; secretary-treasurer,

J. Q. ANDERSON, Barnsdall Oil Company, Bakersfield. JOHN E. KILKENNY, Chanslor-Canfield Midway Oil Company, Los Angeles, was elected representative on the executive committee of the Pacific Section, A.A.P.G.

SAM W. WELLS is employed by Peters Petroleum Corporation, Tulsa, Oklahoma. He was formerly with the Ashland Oil and Refining Company, Evansville, Indiana.

HUGH A. TANNER, formerly with The Ohio Oil Company, is an independent geologist in Midland, Texas.

LOUISE BARTON FREEMAN, formerly with the Department of Mines and Minerals, Lexington, Kentucky, is a geological consultant, 608 Ellsmere Park, Lexington.

CLARENCE M. SALE is assistant professor of engineering in the mathematics department, Texas Christian University, Fort Worth, Texas.

LESTER H. JOHNSON is employed by the Honolulu Oil Corporation, Lubbock, Texas. He was formerly with the Phillips Petroleum Company in Hays, Kansas.

JOHN F. CURRAN is employed as a geologist by the General Petroleum Corporation Los Angeles, California. He served with the Navy during the war and was released to inactive status in 1946.

MAX W. BALL, a past-president of the A.A.P.G., has succeeded RALPH K. DAVIES as director of the Oil and Gas Division of the United States Department of the Interior, Washington, D. C.

L. B. HERRING has been made a vice-president of the Second National Bank, Houston, Texas. He is manager of the bank's oil and gas division.

The Kansas Geological Society has elected the following officers for the ensuing year: E. GAIL CARPENTER, president; LEE H. CORNELL, vice-president; DON W. PAYNE, secretary-treasurer; R. A. CARMODY, director.

The Division of Geophysical Exploration of the Bureau of Mines was transferred on November 16, 1946 to the United States Geological Survey, and absorbed into the Survey's Section of Geophysics. H. R. JOESTING, of the Geological Survey, is geophysicist-in-charge of the consolidated Section. F. W. LEE, chief of the former Bureau of Mines Geophysical Division, will henceforth devote his time to a special program of research in instrumentation.

WALTER BERNOULLI, president of the Museum of Natural History, Basle, Switzerland, died on December 8, 1946, at the age of 61 years. He joined the Association in 1924, when he was chief geologist of the Compagnie Financiere Belge des Petroles.

JAMES PHILIP BOYLE, JR., formerly of Oklahoma City, Oklahoma, is now in Shreveport, Louisiana, with the Skelly Oil Company.

THEODORE G. BECKER is employed by the Stephens Petroleum Company, 2600 Apco Tower, Oklahoma City, Oklahoma.

LEO R. NEWFARMER, formerly stationed in Midland, Texas, with the Shell Oil Company, Inc., is exploration manager of his company in the Houston, Texas, area.

CHARLES A. DURHAM, formerly with the International Ecuadorean Petroleum Company, Guayaquil, Ecuador, is now with the Humble Oil and Refining Company, Midland, Texas.

C. G. HARDIN has resigned from the geological department of W. C. McBride, Inc., and is working as an independent geological consultant, with headquarters in Centralia, Illinois.

DON D. MONTGOMERY has resigned his position of chief geologist for the Macmillan Petroleum Corporation, is to become a consulting geologist at El Dorado, Arkansas. His post office address is Box 747.

Companies and institutions wishing to secure a copy of the Ellis and Messina *Catalogue of Foraminifera* are requested to write without delay to the department of micropaleontology at the American Museum of Natural History in New York City.

J. SMITH ADAIR is an associate geologist engaged in flood-control surveys for the United States Forest Service, Ogden, Utah. He was formerly with the Cabot Carbon Company, Provo, Utah.

O. C. WHEELER is director and chief geologist of International Petroleum Company, Limited, Toronto, Ontario.

J. E. HUPP, formerly with the Glacier Production Company, is a consulting geologist in Cut Bank, Montana, P. O. Box 568.

DON G. BENSON, formerly in Houston, Texas, with the Sinclair Prairie Oil Company, has been transferred to Venezuela, where he is geologist for the Cia. Consolidada de Petroleo, Maturin, Estado Monagas.

VICTOR M. LOPEZ, director of the Geological Survey of Venezuela, was recently awarded the Medal of Freedom by the U. S. War Department in recognition of exceptionally meritorious services performed in behalf of the Allied cause during World War II.

ERNEST GUY ROBINSON has been named by Shell Oil Company, Inc., as manager of exploration and production activities in the New Orleans area. BOUWE DYKSTRA has been appointed to a similar post in the Midland, Texas, area.

PHILIP ANDREWS, until recently chief geologist in Bogota, Colombia, for the Socony-Vacuum Oil Company, has opened a consulting geological office in Boulder, Colorado.

The Alberta Society of Petroleum Geologists met, November 18, in the Palliser Hotel, Calgary, and heard a paper on "Electrical Well Logging" presented by A. A. PEREBINOSSOFF of the Schlumberger Well Surveying Corporation.

The Houston Geological Society was addressed, November 25, by JOHN H. MURRELL, petroleum engineer and geologist, who spoke on "The Oil Fields of the Middle East."

EDGAR K. SOPER has resigned as associate professor of economic geology at the University of California at Los Angeles to become consultant with the Signal Oil and Gas Company, Los Angeles.

ROBERTO SARMIENTO SOTO is the new chief of the Geological Survey of Colombia. A. DEL RIO, former Survey chief, resigned in order to conduct a survey of coal resources of North Santander for the Ministry of Mines and Petroleum.

DISTINGUISHED LECTURE TOUR

PAUL WEAVER, chief geophysicist of the Gulf Oil Corporation, Houston, Texas, spoke before the following societies on the dates listed. His lecture was titled "Formation of Evaporites under Marine Evaporation Conditions."

January	27	Corpus Christi Geological Society, Texas
	28	South Texas Geological Society, San Antonio
	29	West Texas Geological Society, Midland
February	3	South Louisiana Geological Society, Lake Charles
	4	Mississippi Geological Society, Jackson
	6	Southeastern Geological Society, Tallahassee
	10	Appalachian Geological Society, Charleston, West Virginia

11	Ohio State University, Columbus
12	Indiana-Kentucky Geological Society, Evansville, Indiana
13	Illinois Geological Society, Olney
14	Illinois Geological Survey, Urbana
17	Tulsa Geological Society, Tulsa, Oklahoma
18	Kansas Geological Society, Wichita
19	Oklahoma City Geological Society, Oklahoma City
20	Panhandle Geological Society, Amarillo, Texas
21	North Texas Geological Society, Wichita Falls
26	Fort Worth Geological Society, Fort Worth, Texas
27	Dallas Geological Society, Dallas, Texas
28	East Texas Geological Society, Tyler

C. E. DOBBIN spoke on "Unusual Oil Fields in the Rocky Mountain Region" before the Rocky Mountain Association of Geologists, meeting in Denver, Colorado, on February 4.

New officers of the Wyoming Geological Association, Casper, Wyoming, are as follows: president, ROLLAND W. MCCANNE, The Ohio Oil Company; first vice-president, THOMAS C. HIESTAND, Cities Service Oil Company; secretary-treasurer, FRANK A. MORGAN, JR., British-American Oil Producing Company.

PAUL H. BOOTS, assistant manager of the Gulf Oil Company of Colombia, Bogota, was killed in the January 22 crash of an airliner flying over Colombian jungles.

ROY E. COLLOM, Continental Oil Company vice-president in charge of California production operations during the past 15 years, retired December 1. He will continue to serve as the company's director of the Kettleman North Dome Association.

GEORGE S. HUME, of the Geological Survey of Canada, speaking before the Canadian Institute of Mining and Metallurgy, on January 22, revealed that a rich deposit of bituminous sands, possibly containing as much as 500,000,000 barrels of liquid bitumen, has been discovered near Fort McMurray, Alberta.

MICHAEL M. VALERIUS, consulting petroleum engineer and geologist, died January 18, in Shreveport, Louisiana, at the age of 75.

LON L. HUTCHINSON, consulting petroleum geologist, died in Tulsa, Oklahoma, on January 13, at the age of 69.

The Rocky Mountain Association of Geologists (formerly the Rocky Mountain Association of Petroleum Geologists), Denver, Colorado, recently elected the following officers: president, C. A. HEILAND, Heiland Research Corporation; 1st vice-president, ROBERT MCMILLAN, Geophoto Services, Inc.; 2nd vice-president, A. W. CULLEN, Continental Oil Company; secretary-treasurer, N. W. BASS, U. S. Geological Survey.

HODGE MOBRAY FALKENHAGEN died as a result of an automobile accident in Houston, Texas, December 23. He was associated with Independent Exploration Company, Houston.

The Alberta Society of Petroleum Geologists held its annual dinner meeting on January 17 in the Palliser Hotel, Calgary. J. D. WEIR, geology department, University of Saskatchewan, presented his paper on the Pakowki and Milk River formations of Southern Alberta. J. S. IRWIN, consulting geologist, gave a brief outline of the gas and oil sands in the Lloydminster area. The following officers were elected: president, L. M. CLARK, Shell Oil Company of Canada, Limited; vice-president, W. P. HANCOCK, Imperial Oil Limited; secretary-treasurer, D. G. PENNER, Petroleum and Natural Gas Conservation Board of Alberta; business manager, C. O. HAGE, Shell Oil Company of Canada, Limited.

The first South American Petroleum Congress has been postponed until May 12–17, 1947, at Lima, Peru.

A. NELSON SAYRE has been named chief of the Ground Water Division, Water Resources Branch, of the United States Geological Survey, effective December 1, 1946, to succeed OSCAR E. MEINZER who was retired, November 30, after more than 40 years of service in the Geological Survey, and 34 years as chief of the Ground Water Division.

Missouri School of Mines and Metallurgy and the State Mining-Experiment Station offer several fellowships which are open to graduates who have a Bachelor of Science degree, or equivalent, who have had the proper training in mining, metallurgy, ceramics, or geology, and who are qualified to undertake research work. The remuneration for each fellowship is $675 for 9 months academic work, beginning September 1, 1947. Missouri School of Mines and Metallurgy also has open some graduate assistantships in mining, metallurgy, geology, ceramics, chemistry, and physics. These assistantships carry a stipend of $675 for the school year, September 1 to June 1, and require about half-time teaching duties. Applications should be addressed to Dean Curtis L. Wilson, Missouri School of Mines and Metallurgy, Rolla, Missouri.

CAMPBELL MURRAY HUNTER, consulting engineer and oil mining expert, died in London, England, on December 23. He was born in Edinburgh, Scotland, in 1877. He gained the degree of M.A. at Cambridge University.

The following have been elected officers of the Society of Economic Paleontologists and Mineralogists, to take office at the end of the annual meeting in Los Angeles, California, in March: president, JAMES C. WATERS, Sun Oil Company, Dallas, Texas; vice-president, WILLIAM C. KRUMBEIN, Northwestern University, Evanston, Illinois; secretary-treasurer, HENRYK B. STENZEL (re-elected), University of Texas Bureau of Economic Geology, Austin, Texas.

The Stanolind Oil and Gas Company has established at Yale University a fellowship for graduate study in geology, open to students whose interest is either in general geology or in any branch of the subject that has logical application to the petroleum industry. A student appointed to the fellowship will have no obligation in his choice of employment following graduation. For the year 1946–47, the holder of the fellowship is JAMES LEE WILSON, B.A., University of Texas, 1942, M.A., 1944.

The stratigraphy of North Texas was the topic for discussion at the January and February evening meetings of the North Texas Geological Society, Wichita Falls. The society recently acquired a new 16 mm. sound-movie projector.

C. DWIGHT AVERY, of the United States Geological Survey, died at Washington, D. C., February 1, at the age of 69 years.

PEDRO VERASTEGUI MACKEE, geologist in charge of the Zorritos oil field which is owned and operated by the Peruvian Government, is in the United States on a U. S. governmental fellowship to gain experience in American methods of petroleum exploration. He has worked with field parties of the Fuels Section, U. S. Geological Survey, in New Mexico, Utah, and Colorado, and is now in Tulsa studying Mid-Continent exploration methods.

The Houston Geological Society is publishing the results of three study groups: (1) Well Logging on the Gulf Coast, (2) Stratigraphic and Structural Distribution of Coastal Reservoirs, (3) Evaluation of Oil and Gas Properties. These will be published in one volume and off the press by March 15; price, $2.50. Orders may be placed with ARNOLD H. BLEYBERG of The Texas Company, Box 2332, Houston 1, Texas, or A. F. CHILDERS, JR., Box 2100, Houston 1, Texas. Make checks and money orders payable to the Houston Geological Society.

PROFESSIONAL DIRECTORY

Space for Professional Cards Is Reserved for Members of the Association. For Rates Apply to A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma

ALABAMA

HARRY R. HOSTETTER
Core Drilling Contractor
Specialist in Reverse Circulation Coring
100% Recovery
Monroeville, Alabama
P.O. Box 388 Tel. 39-W

CALIFORNIA

J. L. CHASE
Geologist — *Geophysicist*
210 Grand Avenue
LONG BEACH 3 CALIFORNIA
Tel. 816-04
Electrical and Magnetic Surveys

VERNON L. KING
Petroleum Geologist and Engineer
707 South Hill Street
Los Angeles, California
Vandike 7087

JEROME J. O'BRIEN
Petroleum Geologist
Examinations, Reports, Appraisals
Petroleum Building
714 West Olympic Boulevard
McCarthy & O'Brien Los Angeles 15, Calif.

HENRY SALVATORI
Western Geophysical Company
711 Edison Building
601 West Fifth Street
LOS ANGELES, CALIFORNIA

CALIFORNIA

H. W. BELL
Geologist and Engineer
Consultant in Oil, Gas, Mining
for
Development, Production, Appraisal
1136 Wild Rose Dr., Santa Rosa, Calif.

PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
799 Subway Terminal Building
LOS ANGELES, CALIFORNIA

A. I. LEVORSEN
Petroleum Geologist
Stanford University California

ERNEST K. PARKS
Consultant in
Petroleum and Natural Gas Development
and
Engineering Management
614 S. Hope St.
LOS ANGELES, CALIFORNIA

RICHARD L. TRIPLETT
Core Drilling Contractor
PArkway 9925 1660 Virginia Road
Los Angeles 6, Calif.

COLORADO

L. BRUNDALL A. R. WASEM
R. McMILLAN
Geophoto Services, Inc.
Photogeologists and Consulting Geologists
110 W. 13th Ave. DENVER, COLO.

C. A. HEILAND
Heiland Research Corporation
130 East Fifth Avenue
DENVER 9, COLORADO

TEXAS

JOSEPH L. ADLER
Geologist and Geophysicist
Contracting Geophysical Surveys in Latin America
Independent Exploration Company
Esperson Building Houston, Texas

CHESTER F. BARNES
Geologist and Geophysicist
Petroleum Bldg. P.O. Box 266, Big Spring, Tex.

HART BROWN
BROWN GEOPHYSICAL COMPANY
Gravity
P.O. Box 6005 Houston 6, Texas

D'ARCY M. CASHIN
Geologist *Engineer*
Specialist Gulf Coast Salt Domes
Examinations, Reports, Appraisals
Estimates of Reserves
705 Nat'l Standard Bldg.
HOUSTON, TEXAS

PAUL CHARRIN
Geologist and Geophysicist
UNIVERSAL EXPLORATION COMPANY
2044 Richmond Road, Houston 6, Texas
913 Union National Bank Building
Houston 2, Texas

R. H. DANA
Southern Geophysical Company
Sinclair Building
FORT WORTH, TEXAS

CUMMINS, BERGER & PISHNY
Consulting Engineers & Geologists
Specializing in Valuations
1603 Commercial Standard Bldg. Fort Worth 2, Texas
Ralph H. Cummins
Walter R. Berger
Chas. H. Pishny

E. DEGOLYER
Geologist
Esperson Building
Houston, Texas
Continental Building
Dallas, Texas

ALEXANDER DEUSSEN
Consulting Geologist
Specialist, Gulf Coast Salt Domes
1006 Shell Building
HOUSTON, TEXAS

DAVID DONOGHUE
Consulting Geologist
Appraisals - Evidence - Statistics
Fort Worth National Bank Building FORT WORTH, TEXAS

J. E. (BRICK) ELLIOTT
Petroleum Geologist
108 West 15th Street Austin, Texas

R. H. FASH
Vice-President
THE FORT WORTH LABORATORIES
Analyses of Brines, Gas, Minerals, Oil, Interpretation of Water Analyses. Field Gas Testing.
828½ Monroe Street FORT WORTH, TEXAS
Long Distance 138

JAMES F. GIBBS
Consulting Geologist and Petroleum Engineer
505 City National Bank Building
WICHITA FALLS, TEXAS

JOHN A. GILLIN
National Geophysical Company
Tower Petroleum Building
Dallas, Texas

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - - - - J. J. Jakosky
University of Southern California, Los Angeles
Vice-President - - - - - - Cecil H. Green
Geophysical Service, Inc., 1311 Republic Bank Building, Dallas, Texas
Editor - - - - - - - - - - L. L. Nettleton
Gravity Meter Exploration Co.
1348 Esperson Bldg., Houston, Tex.
Secretary-Treasurer - - - George E. Wagoner
Carter Oil Company, Shreveport, Louisiana
Past-President - - - - - - Henry C. Cortes
Magnolia Petroleum Co., Dallas, Texas
Business Manager - - - - Colin C. Campbell
213 Ritz Building, Tulsa, Oklahoma
P.O. Box 1614

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - C. A. Heiland
Heiland Research Corporation
1st Vice-President - - - - Robert McMillan
Geophoto Services, Inc.
136 East Twentieth Ave.
2nd Vice-President - - - - - A. W. Cullen
1024 Continental Oil Building
Secretary-Treasurer - - - - - - - N. W. Bass
U. S. Geological Survey, 314 Boston Bldg.

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

FLORIDA

SOUTHEASTERN GEOLOGICAL SOCIETY
Box 841
TALLAHASSEE, FLORIDA

President - - - - - - - - - - H. A. Sellin
Magnolia Petroleum Company
Vice-President - - - - - - - - B. B. Spaulding
The Texas Company, Box 21
Secretary-Treasurer - - - - - - Lois J. Schulz
The California Company, Box 1118

Meetings will be announced. Visiting geologists and friends are welcome.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - T. H. Shelby, Jr.
Humble Oil and Refining Company

Vice-President - - - - - - George N. Ely
Continental Oil Company
907 Peoples Bank Building

Secretary-Treasurer - - - - - B. F. Murphy
Amerala Petroleum Corporation
Box 2026

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - Shapleigh G. Gray
Consultant, 1713 Esperson Building

Vice-President - - - - - Charles H. Sample
J. M. Huber Corporation
721 Bankers Mortgage Bldg.

Secretary - - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100

Treasurer - - - - - - - - Wayne Z. Burkhead
Union Oil Company of California
1134 Commercial Bldg.

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - - - Thornton Davis
Peerless Oil and Gas Company
2023 Alamo National Building

Vice-President - - - - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Secretary-Treasurer - - - - - Paul B. Hinyard
Shell Oil Company, Inc.
2000 Alamo National Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - C. D. Cordry
Gulf Oil Corporation
Box 1290

Vice-President - - - - - - - R. H. Schweers
The Texas Company, Box 1720

Secretary-Treasurer - - - - - - R. W. Dudley
Pure Oil Company
Box 2107

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - - - Dolph S. Simic
Bay Petroleum Corporation

Vice-President - - - - - - - Lynn L. Harden
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - D. T. Richards
Consulting, 1709 Buchanan Street

Meetings: Each week, Tuesday, 12:30 P.M., Texas Electric Auditorium; Each month, first Thursday evening. Special night meetings announced. All geologists always welcome.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - - W. J. Hilseweck
Gulf Oil Corporation, Box 1150

Vice-President - - - - - - W. A. Waldschmidt
Argo Oil Corporation, Box 1814

Secretary-Treasurer - - - Charles F. Henderson
Stanolind Oil and Gas Company, Box 1540

Meetings will be announced.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2605

President - - - - - - - - Veleair C. Smith
1901 Kanawha Valley Building

Vice-President - - - - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273

Secretary-Treasurer - - - - - - R. L. Alkire
605 Union Building

Editor - - - - - - - - - - J. D. Castner
Box 1433

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P. O. Box 545

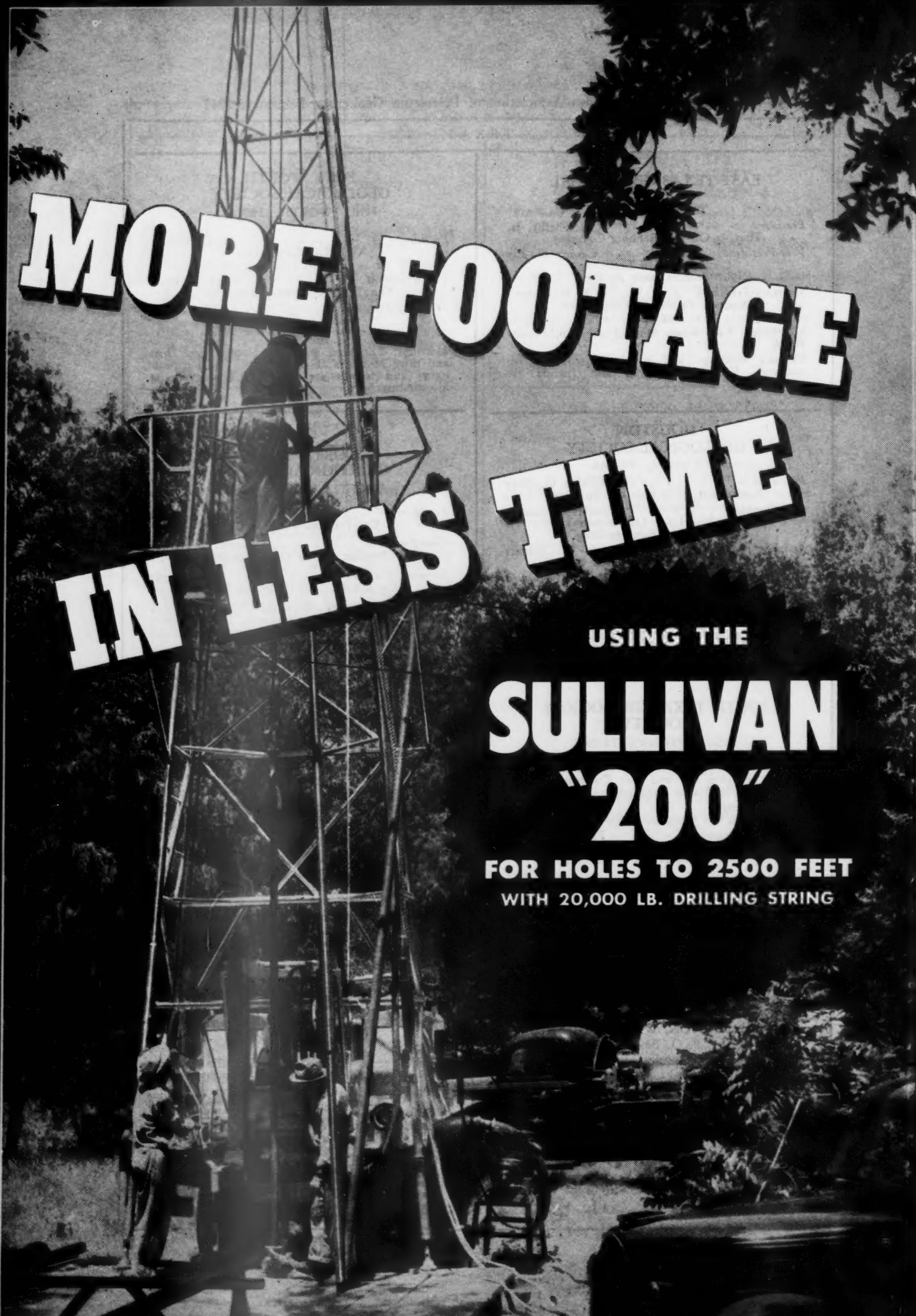
President - - - - - - - - Charles T. Jones
Stanolind Oil and Gas Company

1st Vice-President - - - Rolland W. McCanne
Ohio Oil Company

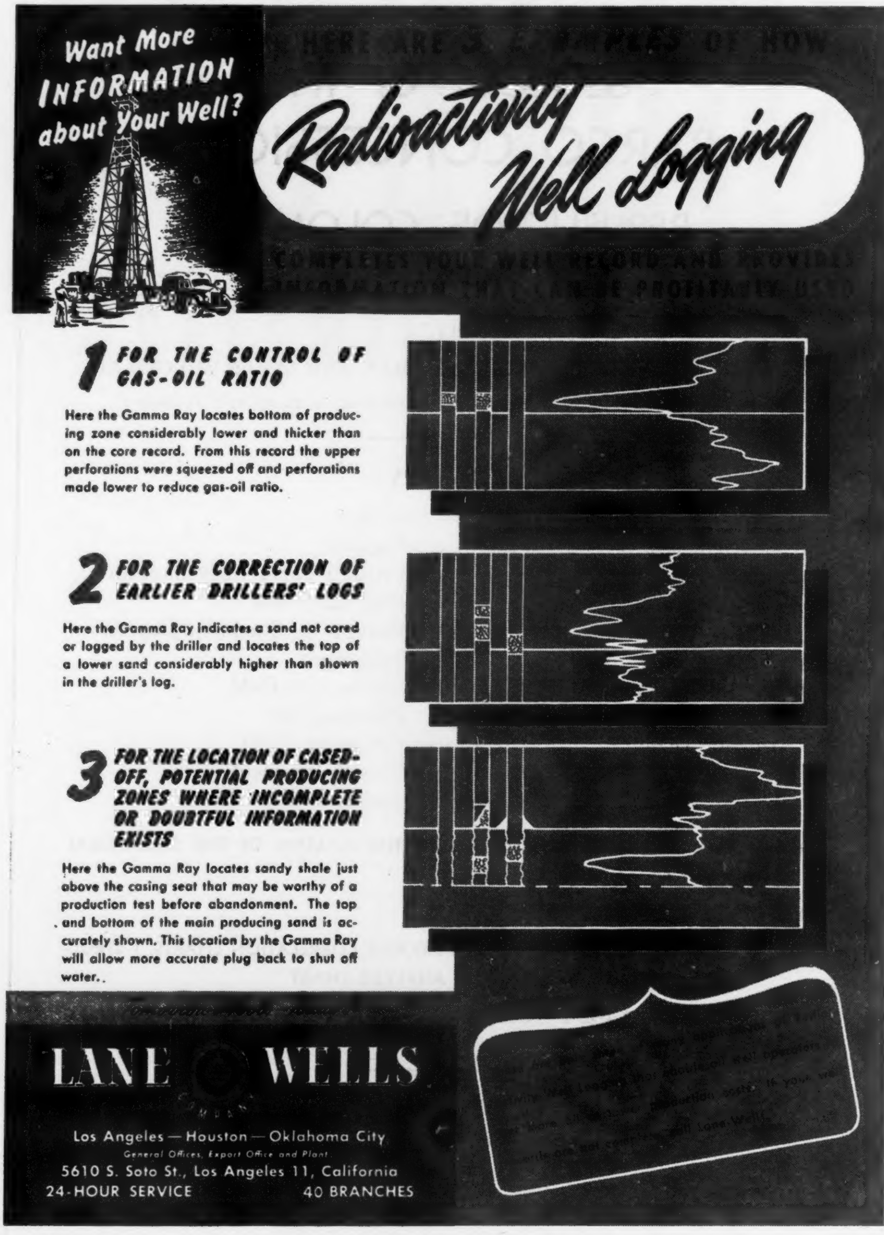
2nd Vice-President (Programs) Thomas C. Hiestand
Cities Service Oil Company

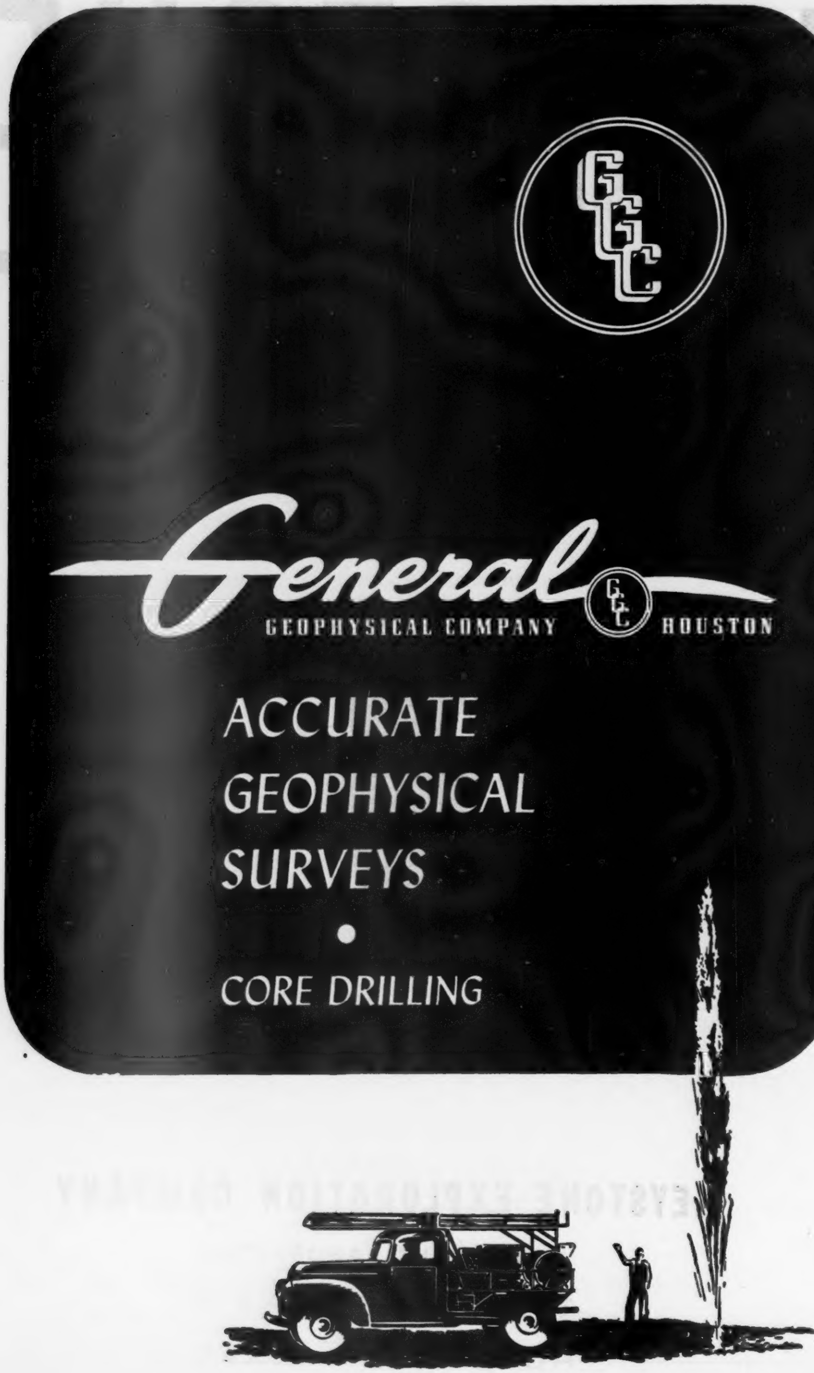
Secretary-Treasurer - - William A. Thompson
The Texas Company

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special Meetings by announcement.



MORE FOOTAGE
IN LESS TIME
USING THE
SULLIVAN
"200"
FOR HOLES TO 2500 FEET
WITH 20,000 LB. DRILLING STRING


Want More INFORMATION about Your Well?
HERE ARE 3 EXAMPLES OF HOW
Radioactivity Well Logging
COMPLETES YOUR WELL RECORD AND PROVIDES INFORMATION THAT CAN BE PROFITABLY USED
1 FOR THE CONTROL OF GAS-OIL RATIO
Here the Gamma Ray locates bottom of producing zone considerably lower and thicker than on the core record. From this record the upper perforations were squeezed off and perforations made lower to reduce gas-oil ratio.
2 FOR THE CORRECTION OF EARLIER DRILLERS' LOGS
Here the Gamma Ray indicates a sand not cored or logged by the driller and locates the top of a lower sand considerably higher than shown in the driller's log.
3 FOR THE LOCATION OF CASED-OFF, POTENTIAL PRODUCING ZONES WHERE INCOMPLETE OR DOUBTFUL INFORMATION EXISTS
Here the Gamma Ray locates sandy shale just above the casing seat that may be worthy of a production test before abandonment. The top and bottom of the main producing sand is accurately shown. This location by the Gamma Ray will allow more accurate plug back to shut off water.
LANE WELLS
Los Angeles — Houston — Oklahoma City
General Offices, Export Office and Plant
5610 S. Soto St., Los Angeles 11, California
24-HOUR SERVICE
40 BRANCHES


GGC
General
GEOPHYSICAL COMPANY
GGC
HOUSTON
ACCURATE
GEOPHYSICAL
SURVEYS
•
CORE DRILLING

BAROID, a high specific gravity weighting agent made from selected barytes, increases the density of rotary drilling fluids for the purpose of controlling formation pressures and preventing caving. Barytes has surpassed all other mud weighting materials in effectiveness.

Baroid Sales Division introduced and developed the use of BAROID which has protected the country's reserves and checked untold damage to life and property by preventing blowouts. Finest laboratory supervision and constant checks upon its field performance continue to uphold the high quality of BAROID as they have done for the past 18 years. These factors, combined with unequaled facilities for field service and distribution, make BAROID by far the most extensively used weighting material available today.

PATENT LICENSES, unrestricted as to sources of supply of materials, but on royalty bases, will be granted to responsible oil companies and others desiring to practice the subject matter of any and/or all of United States Patents Numbers 1,807,082; 1,991.637; 2,041,086; 2,044,758; 2,064,936; 2,094,316, 2,119,829; 2,214,-366; 2,294,877, 2,304,256; 2,387,694; 2,393,165 and further improvements thereof. Applications for Licenses should be made to the Los Angeles office.

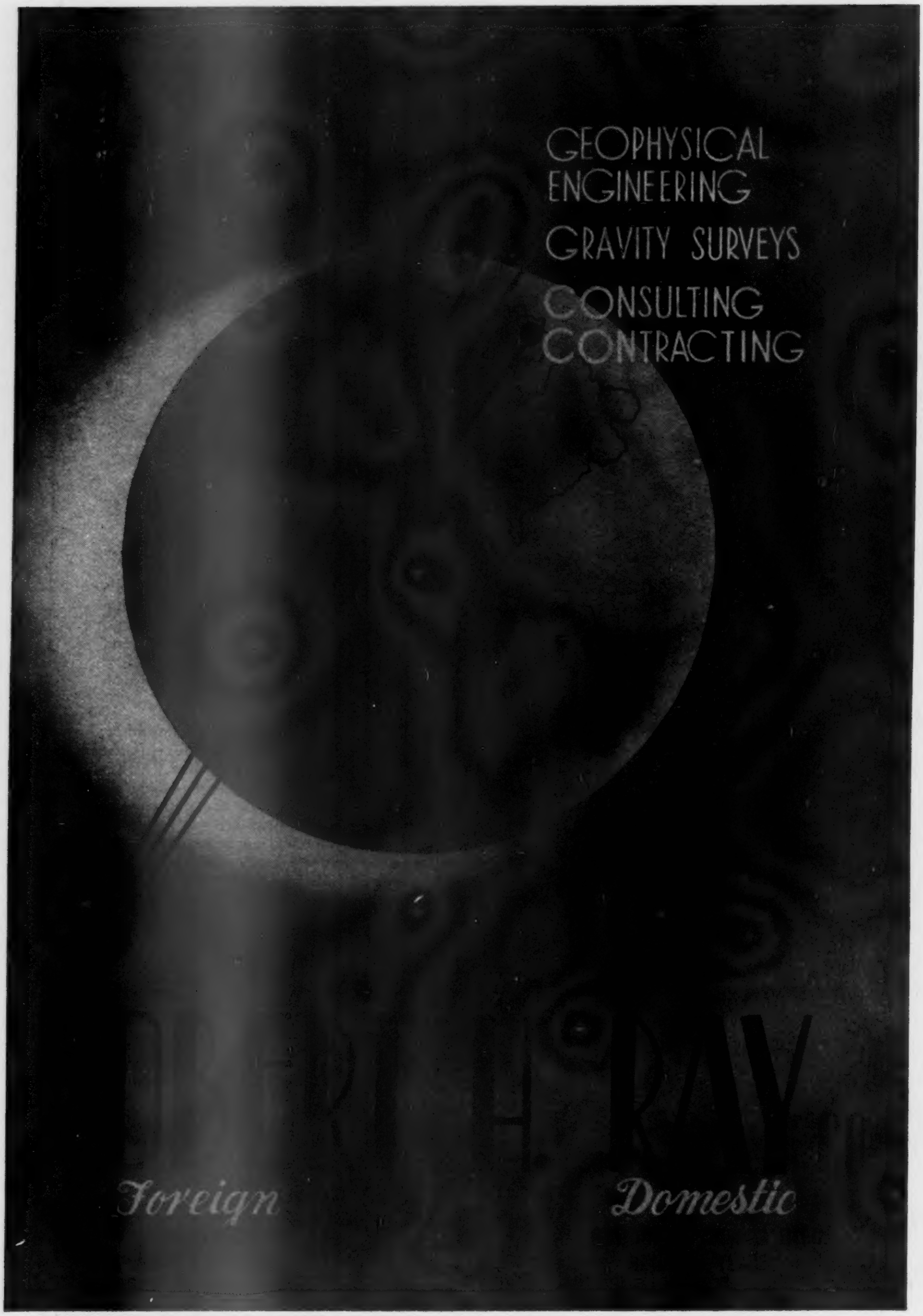
BAROID

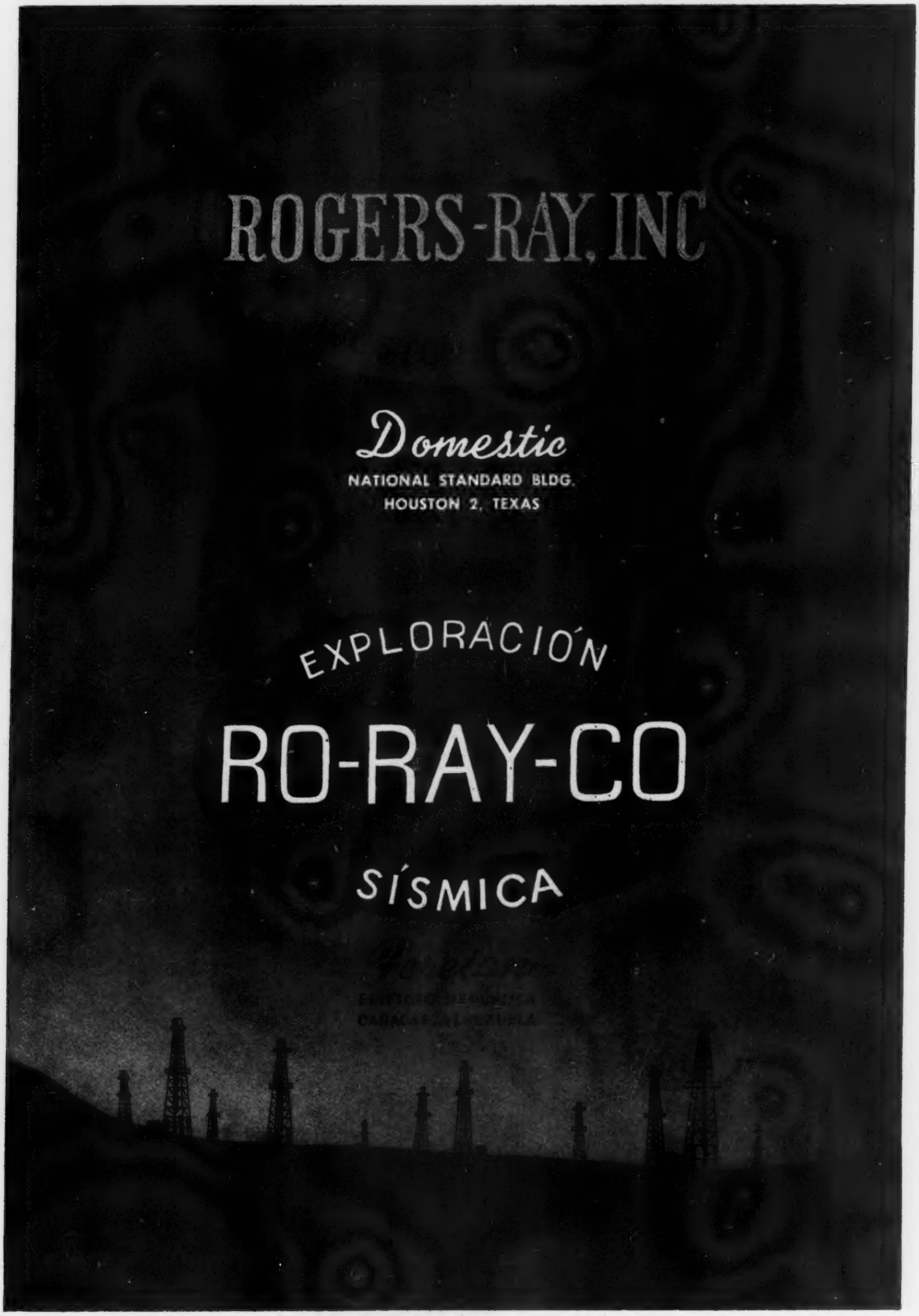
SALES DIVISION

NATIONAL LEAD COMPANY

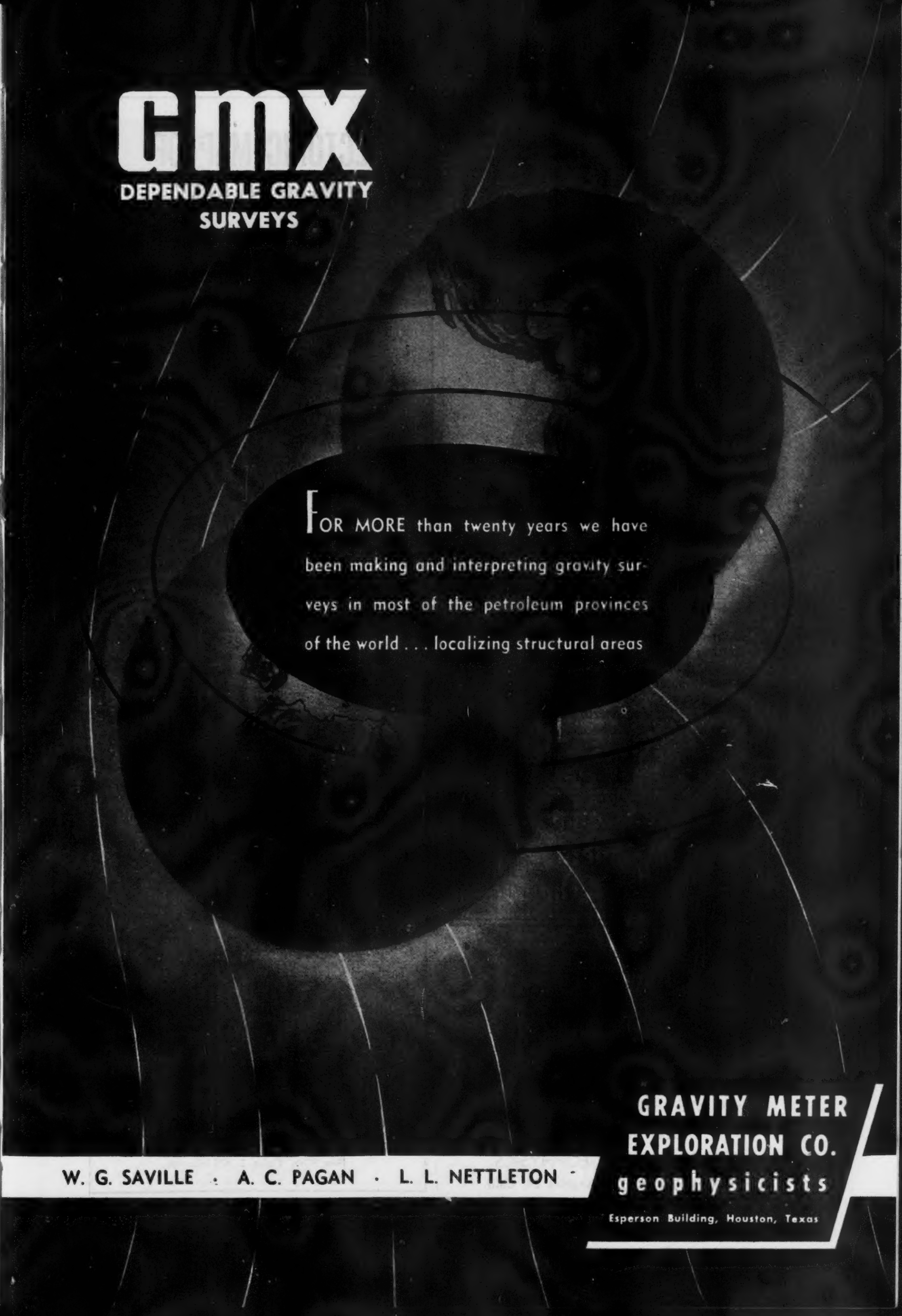
BAROID SALES OFFICES: LOS ANGELES 12 • TULSA 3 • HOUSTON 2

BAROID PRODUCTS: ANHYDROX • AQUAGEL • AQUAGEL CEMENT • BAROCO • BAROID FIBERTEX • IMPERMEX • JELFLAKE • MICATEX • SMENTOX • STABILITE • ZEOGEL • TESTING EQUIPMENT • BAROID WELL LOGGING SERVICE

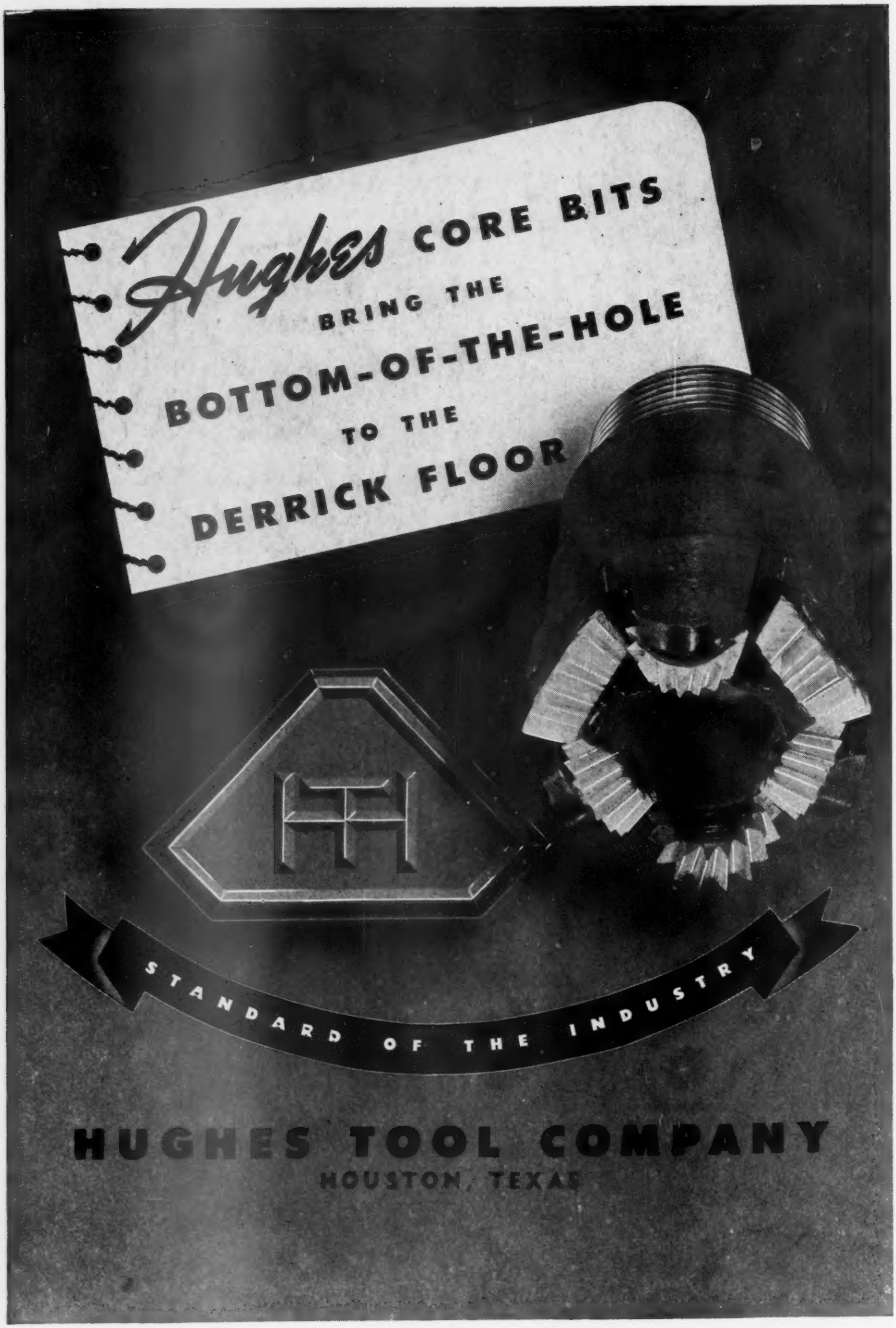

GEOPHYSICAL
ENGINEERING
GRAVITY SURVEYS
CONSULTING
CONTRACTING
RAY
Foreign
Domestic


ROGERS-RAY, INC
Domestic
NATIONAL STANDARD BLDG.
HOUSTON 2, TEXAS
EXPLORACIÓN
RO-RAY-CO
SÍSMICA


The yardstick for measuring the value of any seismograph service is accuracy of interpretation . . . a qualification that comes only with long and diversified experience.
SEISMIC EXPLORATIONS, INC.
Houston, Texas


GMX
DEPENDABLE GRAVITY SURVEYS
FOR MORE than twenty years we have been making and interpreting gravity surveys in most of the petroleum provinces of the world . . . localizing structural areas
W. G. SAVILLE · A. C. PAGAN · L. L. NETTLETON
GRAVITY METER EXPLORATION CO.
geophysicists
Esperson Building, Houston, Texas


THE BIG 3
FOR SEISMIC EXPLORATION
SPIRALOK*
the time-saving cartridge assembly
VIBROGELS*
special explosives for seismic work
VIBROCAP*
the no-lag electric blasting cap
*REG. U. S. PAT. OFF. BY HERCULES POWDER COMPANY
HERCULES
Explosive Department HERCULES POWDER COMPANY 908 King St., Wilmington, Del. XO-62



Hughes CORE BITS
BRING THE
BOTTOM-OF-THE-HOLE
TO THE
DERRICK FLOOR
STANDARD OF THE INDUSTRY
HUGHES TOOL COMPANY
HOUSTON, TEXAS